MACMILLAN'S CANADIAN SCHOOL SERIES

# A BOOK OF GENERAL SCIENCE

HILTON

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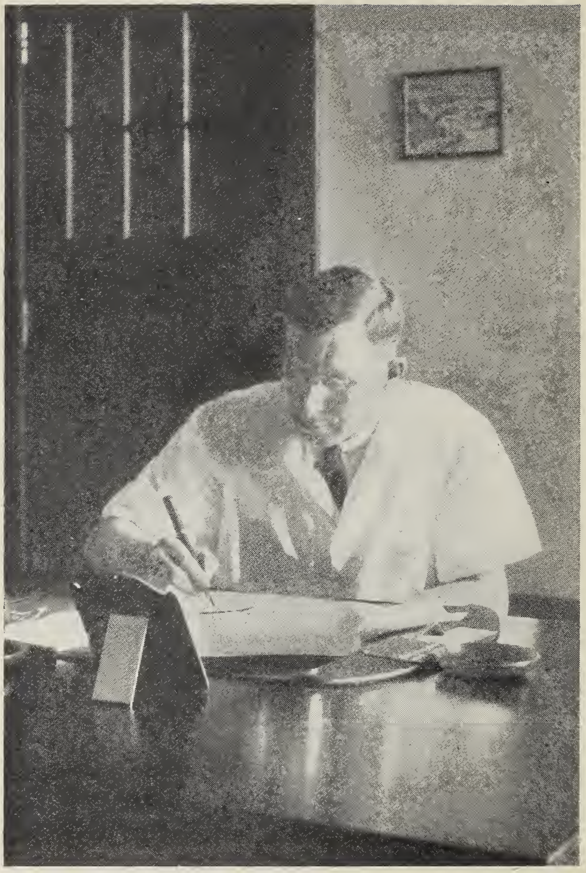

A GREAT CANADIAN SCIENTIST
Dr. F. G. Banting, the discoverer of Insulin for the alleviation of Diabetes.

# A BOOK OF
# GENERAL SCIENCE

BY

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## PREFACE

In 1924 the Department of Education of the Province of Alberta completely revised its High School Curriculum. One of the changes effected was the substitution of a course in General Science for the courses previously given in Physics, Botany, and Zoology in the first year of high school.

It was found impossible to secure from among the published texts one which met adequately the requirements of the course of studies. The writer, therefore, at the suggestion of Joseph M. Scott of the Provincial Normal School at Calgary commenced the preparation of such a text. Considerable encouragement was given by G. Fred McNally, Supervisor of Schools, and Dr. W. G. Carpenter, Director of Technical Education for Alberta.

In writing the book the author has tried to present a readable treatment of the material and also to provide definite experimental work of a nature which can be easily performed with the usual science equipment of a rural school. The author has been constrained to do these two things because: first, no worth-while science can be taught or learned unless supported by an adequate experimental background; second, it is his belief that all junior science work should endeavour to kindle an enthusiasm for the scientific method, and at the same time capitalize educationally the junior student's natural curiosity covering the great phenomena of nature.

During the early stages of the preparation of this book the writer received very valuable help and much

needed encouragement from Dr. R. W. Boyle, Director of the National Physical Research Laboratories at Ottawa, from Dr. John A. Allan, Professor of Geology of the University of Alberta and from Dean R. S. L. Wilson of the Department of Applied Science of the same university. Had it not been for the fine patience, helpful criticism, and kindly encouragement of these gentlemen and of Mr. McNally and Dr. Carpenter, the writer would not have had the courage to proceed.

The author is greatly indebted to Messrs. J. A. Smith and E. L. Fuller, High School Inspectors of the Province of Alberta, for their help in finally casting the material into its present form and for their most careful and critical revision of the final page proofs. Their long experience as teachers and their knowledge of teaching conditions were fully and freely placed at his service. The author is also indebted to Mr. Andrew Morris, a former student of the Edmonton Technical School, for assistance in preparing illustrations.

Special thanks are due to the three Macmillan Companies, of Toronto, London and New York respectively, and to Messrs. A. and C. Black, and the Cambridge University Press, both of London, and The Century Company of New York, for permission to use illustrations from books published by them.

As the book goes to press the writer ventures to hope that his fellow teachers of Science and their students may find in it the material they require and in the case of the latter some inspiration to go further in this field.

M. J. HILTON.

Edmonton, Alberta,
April 18th, 1931.

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## INTRODUCTION

### WHY SHOULD I STUDY SCIENCE?

One very common question asked by students entering high school is, "Why should I study science?" **Why Study Science?** This question is most commonly asked by girls. Before we begin our study of this book let us try to answer this question.

We should study science for many reasons. One reason that suggests itself immediately is that we are living in an age of science. No other age has owed so great a debt to science and scientific methods. So large a proportion of those things which go to make the present so different from the past is the direct result of the study of science and the labours of scientists.

Think of a few of the so-called necessities which differentiate life of to-day from that of, say, one hundred years ago. At that time the railroad was just beginning; there were no such things as electric lights in the home, people depending upon crude tallow dips for artificial lighting, or perhaps going to bed at dark. The roads were in a shocking state, and communication between towns and cities was difficult. It took a week to travel from Glasgow to London. To-day, the same trip is made in a few hours. There were no automobiles or aeroplanes; the electric generator and motor had not yet been invented. Books were few and expensive; magazines, as you know them to-day

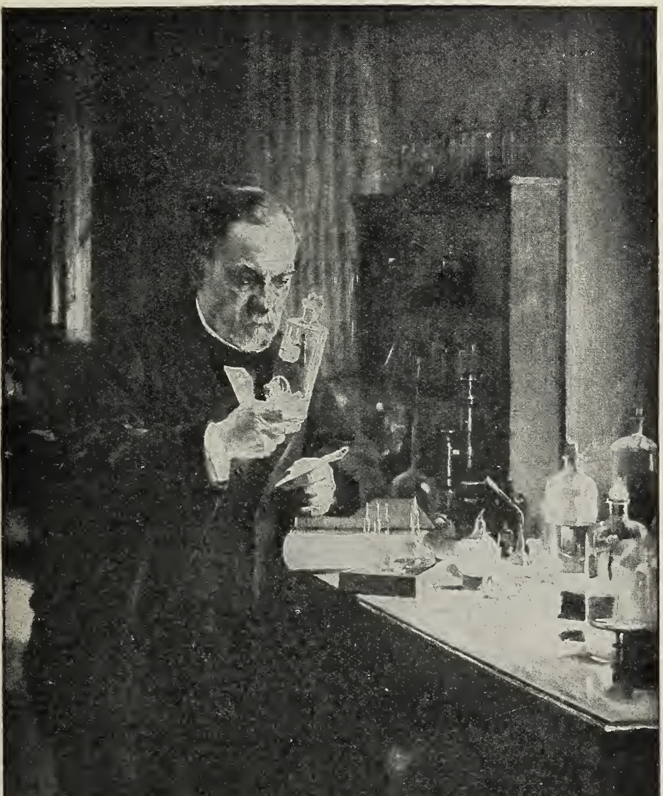
with their wealth of beautiful illustrations and fine paper, were unknown. Clothes at that time were drab and restricted to a very few colours. To-day, thanks to science, clothing is as varied and delicate in its colourings as are the hues of nature.

Less than fifty years ago there were no automobiles, few telegraphs, and fewer telephones. How we should miss them to-day! Imagine a world without motion pictures, radio, wireless telegraphy and aeroplanes. Yet essentially these are products of the twentieth century.

It is the same everywhere,—even in the variety of our foods. Fifty years ago fruits like the banana, so common in our stores to-day, were unknown save to travellers in tropical lands.

It is well within the lifetime of our fathers and mothers that such labour-saving devices as vacuum cleaners, electric toasters, electric irons, typewriters, adding machines, and the like, were invented.

Anaesthetics were almost unknown before 1846. Before that date, most surgical operations had to be performed without them. To-day we hear much about microbes and the science of bacteriology. These things were hardly heard of until the great French scientist, Louis Pasteur, discovered their real nature about fifty years ago. Modern surgery, with its antiseptic and aseptic methods, was unknown. A compound fracture, prior to Lord Lister's application of Pasteur's discovery to surgery, meant either the loss of the limb or almost certain death. The situation is different to-day. Sixty or seventy years ago hospitals were veritable death-traps. Sick people refused to enter them, for in those days the death rate in hospitals was appalling. So serious had the condition in them become, that it was actually proposed to burn them all down



*Courtesy N. Y. Academy of Medicine*

Fig. 1.—Louis Pasteur, 1822-1895
"He saved more lives than Napoleon took in all his wars."

and never build any more! Sanitary conditions were fearful. Water had not yet been pressed into the service of man for general purposes. Dangers lurking in drinking water were unsuspected, and filth was everywhere. Fearful epidemic diseases scourged towns and cities with alarming frequency. To-day all is changed and for the change we must thank science and the scientific method.

**What is Science?**

Science is most often defined as the orderly arrangement of knowledge. This is a very good definition, for the distinguishing feature of science is *order*. The knowledge which the modern scientific world possesses is of such great extent that its use would be greatly hindered if it were not separated into departments. Just as in the case of a public library the books are arranged in sections, so modern science is divided into departments, and the knowledge gained from observation, experiment and thought is classified within these departments.

For example, *Mathematics* is the great department of science which relates to our knowledge and observation of numbers. *Chemistry* is the department which deals with the composition of material things and their actions and reactions towards each other. *Biology* deals with living things. *Psychology* is the study of the mind and the laws of thought. *Sociology* is a great department of science dealing with the study of social relations. *Physics* deals with forces acting upon matter.

It must always be remembered that these divisions are made merely for our own convenience and are all part of the larger unit of knowledge called Science. They are like the divisions of a great modern development in business—the department store. There we

see the clothing department, boot and shoe department, hardware department, notions department and others, not as separate businesses but as parts of the large whole, the divisions into departments being solely for the convenience of the management and the customers.

It is part of the purpose of a General Science course to reveal to the young student, just beginning the study of science, the essential oneness of the different branches he will study in more detail as he progresses through school or university.

To sum up, then, the study of Science is very valuable to us because

1. It teaches that by greater knowledge of, and by increased control of, the natural forces affecting existence, the welfare of mankind may be improved.

2. It helps the student to make correct interpretations of observed facts by increasing the capacity for independent thinking, by developing the ability to gather and verify and to classify data.

3. While enlarging the outlook and stimulating the imagination, it fosters a love of truth and provides abundant knowledge of practical value in everyday life.

# A BOOK OF GENERAL SCIENCE

# PART ONE
# MEASUREMENT

## CHAPTER 1

## MEASUREMENT

**What is Measurement?**

Everyone measures, yet few people know how to measure exactly, and still fewer people realize the great importance of measurement in every branch of modern life.

*Measurement* is used every time we make a purchase. Every time mother makes a cake she measures. A visit to the dressmaker or tailor involves the taking of quite accurate measurements. If you wish to cover the kitchen floor with linoleum, or purchase a carpet for the living room, you think of measurement first.

The whole history of planning and building a house is a story of measurement. First, a plan has to be decided upon, and a design made to fit the plan. This is made by an architect or a draughtsman who, by measurement, fits every part into the whole and makes a picture of the house. The contractors use the plan, and are able by measuring to determine the different quantities and sizes of material required. They are also able to measure the quantity of labour necessary, and to state the time it should take to complete the job. In addition they are able to fix the price.

### Modern Transportation Depends Upon Measurement

The operation of a great railroad system is only made possible by accurate time measurement. Navi-

gation is dependent principally on our ability to make accurate measurements of the height of the sun or some star above the horizon, and to compute the difference in time between noon at one place and at a fixed place, namely, Greenwich, England. The necessary measurements are made by two groups of observers—the ship's officers and the astronomers. From the measurements made in the observatories, tables showing the times of high and low tide at different harbours are compiled for each day of the year. Other tables made by the astronomers give the positions of the sun, moon and stars for every day of the year. By using these tables and comparing them with their own observations, the ship's officers find their position at sea. We see, then, that transportation, that "Magic Carpet" of modern commerce, relies to a great extent upon measurement.

### The Efficiency of Modern Machinery Depends Upon Precise Measurement

This is the age of machinery. Never before in the history of the world has man made so much use of machines. One of the great troubles which beset the early engineers of this present age was the lack of precise measuring instruments and the skill to use them. To-day modern machines, tools and mechanical measuring devices enable machinists to make similar pieces which do not vary more than *one one-thousandth* of an inch from each other. In some cases where extreme accuracy is demanded the limit is occasionally *one ten-thousandth* of an inch. Out of the development of such mechanical perfection have arisen those marvels of modern engineering, the high-speed electrical machine and the internal combustion engine.

## The Greatest Achievements of Modern Science Are The Result of Accurate Measurement

It is impossible in this place to do more than indicate briefly one or two instances of how precise measurement has helped scientists in making their great discoveries.

Perhaps the most important instrument for making accurate measurements of mass is the balance. This is one of the oldest of measuring instruments. In the hands of the chemists it has revealed the mysteries of chemical combinations. It has also demonstrated to us the great truth, that "matter can be neither created nor destroyed". The measurements of the balance have enabled chemists to create new colours, to imitate and surpass the perfumes of the flowers, to produce the great explosives with which our engineers blast paths through the mountains, and win the stored treasures of the mine and well.

Another measuring instrument is the spectroscope. The measurements made with this instrument in the hands of the astronomer, the physicist, and the chemist, are responsible for wonderful things. For example, by its aid, astronomers discovered a new element, a gas called helium, in the sun, and then by its help chemists searched for and discovered the same gas on the earth. In the hands of the physicist spectroscopic measurements are revealing light and heat which are not perceivable by our own unaided senses, but which may soon be harnessed to do useful work for man.

**A Definition of Measurement**

Measurement may be defined as the art of determining the size of anything by comparison with another quantity called the unit. For example, we may measure lengths by comparing them with that particular length which we call a "foot", and

we say that a given length is equal to, or will contain, so many feet. In a similar way we measure weight by comparing a particular mass with another certain mass which we call a pound weight and so on. Now any particular quantity, selected as a standard for measuring other quantities of like kind, we term a *unit of measurement.*

*Units,* then, may be defined as those quantities in terms of which we express a measurement.

We classify units as either fundamental or derived. What do we mean by these terms?

*Kinds of Units*—If any measurement be carefully considered, it will be readily seen that it always consists of a determination of length, mass, or time, or of some combination of these quantities. Such quantities, then, are of primary importance, and certain of the units used in measuring them are called fundamental units.

*Fundamental units,* are those special units of length, mass and time from which all other units are derived. They are the foot, the pound, the second, the centimetre and the gram.

*Derived units* are then easily defined as those obtained from one or more of the fundamental units.

Derived units may be obtained from the fundamental units in several ways. The *acre* is a derived unit. It is the area of any piece of land whose length and breadth in feet multiplied together will yield 43,560 square feet. Therefore, since the *acre* unit depends upon that fundamental unit the *foot,* it is called a *derived unit.*

**Systems of Measurement**

There are two common systems of making measurements. These are the *British system* and the *Metric system.* These systems are based upon

two different methods of determining the fundamental units of length, mass, and space. In the *British system* the fundamental units selected are the foot, pound, and second. This system is therefore also known as the F.P.S. or foot-pound-second system.

In the *Metric system* the centimetre, gram, and second are selected as the fundamental units. In consequence this system is spoken of as the C.G.S. or centimetre-gram-second system.

The British system is used throughout the British Empire and the United States for all measurements other than the scientific ones. Nearly every other civilized country uses the Metric system for all measurements.

## Comparison of the British and Metric Systems of Measurement

Each system has its own peculiar advantages and disadvantages when applied to certain types of work.

The British system has the advantage of large units, and is therefore well suited to the large-scale measurements demanded by commerce and engineering. It has the following serious disadvantages:

1. It uses the duodecimal (twelves) system of notation instead of the more convenient decimal system.
2. There is no uniformity in the form of the tables.
3. The multiples and subdivisions of the units are not easily recognizable as such by their names.
4. It is needlessly complicated.
5. It uses mixed numbers as multiples and subdivisions of the units, e.g., $5\frac{1}{2}$ yards=1 rod. This introduces more arithmetical difficulties than are necessary in such processes as reduction, addition, subtraction, multiplication, and division.

6. No simple relation exists between the standards of length, mass, and volume.

7. It is used only by the English-speaking nations, and then for only part of their measurements.

The Metric system has the following great advantages:

1. It uses the decimal system of notation.

2. In every table the same form and the same prefixes for the multiples and subdivisions of the units are used. They are thus made readily recognizable by inspection.

3. Its standards of length, mass, and volume bear a simple relation to each other.

4. It does away with the addition, subtraction, multiplication, and division of compound quantities, and simplifies reduction.

Its great disadvantage lies in the smallness of its units, which make it cumbersome when applied to large-scale measurements. Another disadvantage is that recurring decimals are very frequent.

**Standards of Measurement**

When man started to interchange his commodities, land and ideas, it was soon found necessary to adopt some particular unit as a *standard*, so that values might be compared. Unfortunately there was at first no real co-operation about these standards, so that confusion ran riot. In England, there were barons' weights and measures, local variations of pounds, gallons, bushels, and every other measure used in the buying and selling of goods. Similar conditions existed in every other country.

This disordered state of affairs resulted in great restriction of trade and industry and cried out for remedy. The final result was that certain units were selected by parliament. These are called the *legal*

*standard units.* Observance of these is strictly enforced by law, and their accuracy is guaranteed by a system of inspection of weights and measures. Examples of such standards are: the Imperial Yard, the Imperial Pound, the Imperial Gallon of the British Empire, and the International Litre, which are all legalized by parliamentary enactments in nearly every civilized country.

In addition to these *legal standards,* the demands of commerce have led to other types of standard units being adopted. These *commercial standards* do not rest upon any legal enactment, but are arranged by mutual agreement among the people concerned. Examples of such standards are the standard screw threads for bolts and pipes.

Standard Units, then, may be defined as those units which are set apart for purposes of comparison. They are of two kinds:

1. *Legal Standards,* those standards specified by law.
2. *Standards,* units which are selected by mutual arrangements among the people directly concerned in their use.

The selection, preparation, and maintenance of the legal standards of a country are of the greatest importance to the citizens of that country, since the commercial life of the nation depends upon the accuracy of these standards. Governments of all civilized countries, therefore, maintain special departments, whose duty it is to see that these standards are strictly kept in all manufacturing and commercial transactions.

### The Five Standard Units

1. *The British Standard Yard*—The present standard was constructed in 1845, after the destruction of

the previous standards by a fire in the Houses of Parliament in London. It consists of a rectangular bar of bronze, into which are inserted, at about one inch from each end, two gold studs, each of which is engraved with a transverse line. Parliament has defined the yard to be the distance between the centres of these lines at a temperature of 62° Fahrenheit. This standard is kept in a fire-proof safe at the Standards Office in London. Copies of it are deposited in the House of Commons, the Royal Society, the Royal Mint, and the Royal Observatory at Greenwich. This practice is followed in order to avoid a recurrence of the destruction of the standards, as the making of a standard is a difficult, lengthy and expensive process.

Each of the British Overseas Dominions is provided with a copy which is kept by the particular department of the Government charged with the administration of the Weights and Measures Act. The Canadian Standards are kept in the Standards Office of the Department of Inland Revenue, Ottawa.

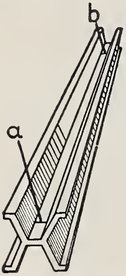



**Fig. 2.—The International Metre Bar**

The distance is measured between two lines ruled across the web.

2. *The Standard Pound* is the weight of a certain cylindrical mass of platinum kept at the Standards Office in London, England. Copies of it are preserved at the same places as in the case of the Standard Yard, including the various Overseas Dominions.

3. *The Standard Metre*—Originally this standard was constructed to represent the one ten-millionth part of the distance from the Pole to the Equator, measured along the meridian passing through Paris. An error was made in the measurement of this dis-

tance, so that the Standard Metre does not really represent this fraction of the circumference of the earth.

The original Standard Metre was a bar of platinum just a metre from end to end, about one inch wide and about one-sixteenth of an inch thick. As time went on, the French Government experienced great difficulty in making exact copies of this rod; so, as the demand for copies kept increasing, it was decided to construct a new standard bar.

In 1875 there met in Paris an international committee of delegates officially appointed by various national governments. This committee established the International Bureau of Weights and Measures at Sèvres, near Paris, and the different nations contributed towards its upkeep. This Bureau proceeded to produce a new standard metre which is called the *International Standard Metre*. The Bureau constructed thirty-one standard metre bars and forty standard kilograms. These were all completed in 1899, when one of the bars which most nearly corresponded with the original metre was chosen by the committee as the International Standard Metre.

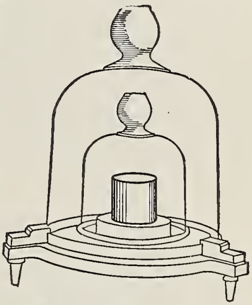


**Fig. 3.—Standard Kilogram Weight**

The new bars are made of an alloy of platinum and iridium, which is hard and durable. They are of a peculiar shape, as shown in Fig. 2. This shape was selected on account of its great stiffness. The metre is defined to be the distance between the centres of the two transverse lines (marked *a* and *b* in the illustration) engraved on the upper face of the cross bar when the rod is at the temperature of melting ice.

4. *The Standard Kilogram*—The kilogram is the mass of a certain piece of platinum which is carefully preserved in the Archives at Paris. It represents the mass of one litre of pure water at a temperature of 4° Centigrade.

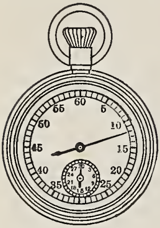



**Fig. 4.—A stop watch which measures time to one-fifth of a second**

As in the case of the metre, difficulty was found in reproducing this standard. So, from the copies made by the International Bureau, the Committee selected one which most nearly coincided with the original, and this is now the *International Standard Kilogram.* It is also kept at Sèvres.

5. *The Standard Second* is obtained by dividing the average length of the days for an entire year by 86,400. It is therefore defined as the one eighty-six thousand and four hundredth part of a mean solar day.

## QUESTIONS

1. What is measurement?
2. Give some instances which clearly show the importance of measurement in modern life.
3. Show how measurement makes possible the great achievements of our modern transportation systems.
4. Give some instances of how accurate measurement has resulted in great and useful scientific discoveries.
5. What is a unit of measurement?
6. Why are some units called fundamental units and others derived units?
7. Which are fundamental units and why?
8. What do you understand by the British or F.P.S. system of measurement? By the Metric, or C.G.S. system?
9. Compare the British and Metric systems of measurement.
10. What is meant by a standard of measurement? Why was it found necessary to adopt standards of measurement?
11. What are standard units?
12. How does a legal standard differ from a commercial standard? In what respects are they similar?
13. What are the five Fundamental Standard Units?

14. Define the legal standard length for Great Britain and the British Overseas Dominions.

15. Explain how the standard metre was originally constructed, and what it was intended to represent.

16. Define the International Standard Metre and tell why the original standard was abandoned.

17. Define the British Standard Pound.

18. Define the International Standard Kilogram.

19. Explain how the Standard Second is derived.

20. What connection is there between the units of length ~~and~~ weight in the metric system of measurement? What advantage is afforded by this connection?

## CHAPTER II

## EXERCISES IN MEASUREMENT

It is a fact that very few people indeed can measure with any reasonable degree of accuracy without training and considerable practice. The difficulties encountered when we try to measure are mainly due to three factors: instrument errors, parallax, and personal errors.

**Instrument Errors**

Continual use of an instrument causes wear and consequently introduces a source of error. The graduations of an instrument, even in the most expensive ones, are never exactly in ratio to each other. In the cheaper forms of instruments, such as are in general use by workers, the differences in the sizes of the graduations are often so great as to be easily noticed on inspection. Examine your ruler and see if this statement is not correct. You will readily understand that, as some graduations are too large while others are too small, an average of several graduations will be more nearly right than any single one. Scale errors can therefore be lessened, and almost eliminated, by making several different measurements of the object, using a new section of the scale each time, and averaging the measurements.

**Parallax Error**

This is one of the commonest sources of error in measuring, and one which produces very serious mistakes. Parallax is the apparent change in the position of an object due to a change in the position of the

observer. Study Figure 5 which shows how the reading of a measurement is affected by changing the position of the measurer's eye.

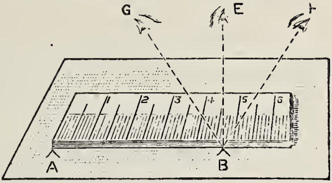


Fig. 5.—Error Due to Parallax.

It will be seen that the thicker the scale the greater the possible error by parallax. Parallax errors are entirely avoided, either by bringing the eye of the observer directly above the point under observation, or by placing the scale graduations in contact with the object. The second method is the better one, since it is not always possible to get the eye vertically above the object. It is with the idea of avoiding parallax errors that rulers and draughtsman's scales are made with bevels. The cure for parallax, then, is to take care to make the graduations of these scales touch the object.

**Personal Errors**

These are the errors due to the personal traits of the person who is making the measurement. Each of us has peculiarities which make us see, think, and do things in a manner which differs from that of other people. This applies in measuring as well as in other things. To reduce such errors to the lowest possible amount one must exercise great care, proceed cautiously and systematically, and take the average of several readings. Form the habit of checking a reading before recording it.

**Experiment 1.**—*To determine the number of centimetres in one inch.*

*Apparatus Required:* An "H" pencil, with a very sharp point, and a ruler graduated in tenths of an inch and in centimetres. The boxwood scale supplied with the geometry sets is very suitable.

*Procedure:* Draw three lines exactly 5 inches, 3 inches, and 2 inches long. Place the centimetre side of the scale alongside each in turn, and measure its length accurately. Estimate to the second decimal place if the end of the line does not exactly coincide with a division on the scale. Be careful to hold the scale so that the graduations *do* touch the object. If you are using an ordinary wooden ruler, do not use the end division of the scale, as the ends of the rule are apt to be a little worn. Be sure to use a different part of the scale for each reading.

*Data:* Tabulate your results and calculate the number of centimetres in one inch.

*Error:* The calculations of highly skilled experimenters, obtained by making a large number of readings with very accurate instruments, have shown that there are 2.54 centimetres in one inch.

See how close you can get to the correct figure.

**Experiment 2.**—*To measure the circumference of a given circular object.*

*Apparatus Required:* Accurately made wooden or metal discs from 1 to 4 inches in diameter, large coins or cylindrical cans, strips of paper; a sharp needle and a scale. (A metre stick graduated in both inches and millimetres is best.)

*Procedure:* Wrap a strip of paper tightly around the object, and prick a small hole with the needle through the overlapping portion and the strip next to the object. Then, laying the scale on it, measure the distance between the two holes, first in inches and then in centimetres, estimating to the second decimal place where necessary. Repeat three times for each, and use a different part of the scale each time. Be very careful to hold the scale so that the graduations touch the paper. Tabulate the results and take the average.

*Proof:* Divide the average length in centimetres by 2.54 and compare this result with the average length in inches.

**Experiment 3.**—To *discover if there be a constant relationship between the diameter and circumference of all circles.*

*Procedure:* Using the methods learned in the two previous experiments, determine the diameter and circumference of three circular objects of different diameters. Divide each circumference by its diameter. Tabulate the results. What is your opinion?

**Experiment 4.**—*To find the area of a circle.*

*Apparatus Required:* Compasses, squared paper, scale graduated in inches and centimetres.

*Procedure:* Draw a circle wih your compasses, with a radius of 3 centimetres if your squared paper is metric, or 1 inch if it be in tenths of an inch. Count the number of complete small squares enclosed by the circumference of the circle. Count also the number of incomplete squares and divide this number by 2. Add together the numbers so obtained; from these data calculate

the area of the whole circle in square centimetres or square inches.

Repeat, using circles of 5 and 6 cm. or 3 and 4 inches radius, and tabulate your data.

*Proof:* The mathematical formula for computing the area of a circle is $\pi r^2$. ($\pi = 3.14159$, r=radius.)

Compute the area of each circle by this formula and compare your results.

**Experiment 5.**—*To measure the area of an irregular plane figure.*

*Apparatus Required:* Squared paper, a scale, and a pencil.

Using the method of Experiment 4, determine the area by counting squares.

*Uses:* For the determination of the areas of countries, lakes, etc., on maps where the scale is known.

**The Measurement of Volumes**

Volume is the amount of space occupied by a body. In the British system there are a good many units in common use by which this quantity is measured, e.g., the cubic inch, cubic foot, pint, gallon, peck, bushel, etc. One of the serious disadvantages of the British system is that the pint, gallon, peck and bushel do not bear any simple relation to the units of length. This lack of simplicity makes the British system awkward to use when calculating.

In the Metric system the units of volume are the cubic centimetre and the litre. Now the litre is the common unit used for the measurement of all liquids, and it contains 1,000 cubic centimetres. Thus there is a simple relation between the units of volume and the units of length. This makes the calculations of the Metric system easy. We shall therefore carry out our exercises in the measuring of volumes in the Metric system.

**Experiment 6.**—*To measure the volume of a cylinder, and to prove the correctness of the formula: Area of the base multiplied by the height equals the volume of a cylinder.*

*Apparatus Required:* A cylindrical metal block, callipers, metric scale, overflow can and a graduate reading cubic centimetres.

*Procedure:* Using the callipers and the rule, find the average diameter and height of the cylindrical block in centimetres, taking at least three measurements of each dimension.

Tabulate the data.

Calculate the volume of the cylinder in c.c. Enter the result in your note book.

Now take the overflow can, place the finger over the spout, and fill with water to a point higher than the level of the spout. Place the can on a level surface, remove the finger and let the excess water run into a beaker. Throw this water away. Next hold the graduate under the spout and carefully lower the cylinder into the can until it is entirely submerged. This must be done gently, or you will splash too much water out of the overflow can and spoil the result. Wait for the water to stop running out of the spout. Place the graduate on the table and take three readings. Record each result and average. Compare the calculated volume with the volume obtained by displacement. They should be very close.

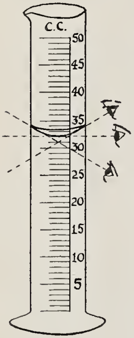



**Fig. 6.—Graduated Glass Cylinder**

*How to Read a Graduate:* Water in a narrow glass vessel turns up at the edge, and two curved lines are seen. It is the rule in reading the levels of liquids in a tube *to take the lowest surface.* Parallax is a common source of error in reading graduates, so care must be taken to keep the eye on the same level as the lowest point of the curve. Study Figure 6 and you will soon realize how big an error you can introduce by not remembering about the parallax.

Having now tested the accuracy of the displacement method of measuring the volume of a solid, we can confidently apply this method to the determination of the volume of objects whose shape is so irregular that direct measurement with a scale is impossible.

**Experiment 7.**—*To determine the volume of any irregular solid by the displacement method.*

*Apparatus Required:* Irregular masses of stone, iron, etc., and a graduate.

By applying the principle of Experiment 6 work out a method of procedure. Show this to your teacher, and if approved carry out the experiment.

*Question:* Suppose you wanted to find the volume of an irregular solid which dissolves in water. How could you find it by this method?

The mass of a body is the quantity of matter contained in it. If we have two pieces of the same sort of

material, but different in size, we can say the larger piece has the greater mass. If, however, we compare

**The Measurement of Mass**

different sorts of material, say a piece of lead with a piece of aluminum, size no longer is a sufficient indicator as to which possesses the greater mass, because a small piece of lead may have the same mass as a much larger piece of aluminum. How, then, can we measure mass?

*The Chemical or Physical Balance* is the instrument used to measure masses. Carefully study Figure 7 and read the description of it. The masses which we use as units for measuring mass are called weights. Figure 8 shows the usual type of set found in a school laboratory. Carefully study such a set, paying particular attention to the system of marking the *subdivisions of the gram.*

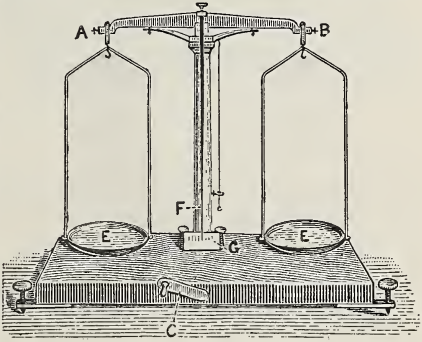



**Fig. 7.—A Common Form of Laboratory Balance.**

*Description:* The brass beam, *AB*, is supported at its middle line on a knife-edge of hard steel, which, when the balance is in use, rests on a true surface of similar steel. The hooks to which the pans are attached are likewise provided with a V-shaped groove of hard steel, which also, when the balance is in use, rests upon the knife-edges on the upper parts of the beam. To the middle of the beam is attached a pointer, *F*, the end of which moves in front of an ivory scale, *G*, fixed at the bottom of the upright which carries the beam. When not in use, the beam and hooks are lifted off the knife-edges by turning the handle *C*.

**Rules for Weighing**

In weighing, great care must be taken to develop systematic habits and to concentrate on the job in hand. No one can weigh accurately whilst talking, or if he is being disturbed by others. The observance of the following rules is essential for accurate work in weighing.

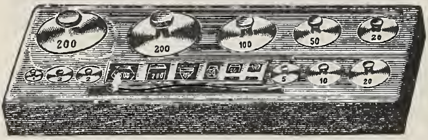



Fig. 8.—Common Type of Metric Weights Used in School Laboratories

1. Sit squarely in front of the needle of the balance to avoid parallax errors.

2. See that the pans and all parts are clean by dusting with a camel's hair brush.

3. See that the balance is level; notice the levels or plumb bob.

4. Before weighing, test the balance to see if it is swinging true. If not, use the adjustment screws until it is.

5. Bring the balance to rest, and place the object to be weighed on the left-hand pan and the weights on the right-hand pan.

6. Never place a substance directly on the pan; always use a weighed watch glass or other vessel.

7. Be sure any apparatus placed on the pan is clean and dry.

8. Never place on the balance any piece of apparatus which is hotter or colder than the balance. (This alters the length of the arm on that side, and so would throw the balance out of adjustment.)

9. Never put anything on or take anything off the scale pans while they are swinging.

10. All movements must be gentle.

11. Always handle the weights with the forceps; never touch them with the fingers.

12. Always enter the weights in your note book before removing them from the pan, and check them as you return each weight to the box.

13. Leave the balance in the position of rest.

14. See that every weight is returned to its proper compartment in the box; replace the forceps; close the box.

**Experiment 8.**—*To find the weight of 1 c.c. of water.*

*Apparatus Required:* Balance, set of gram weights, pipette, beaker, and container with distilled water.

*Procedure:* Carefully clean the beaker and pipette. Make sure the beaker is thoroughly dry. Determine its weight and record the result. Using the pipette, transfer 20 c.c. of water from the container into the beaker, re-weigh and record the result. Subtract the weight of the beaker and from the result calculate the weight of 1 c.c. of water. Discard the water and dry the beaker. Transfer 30 c.c. of the water from the container into the beaker. Weigh again as before and record the result. Calculate the weight of 1 c.c. of water.

Repeat the experiment, transferring 40 c.c. of water to the beaker, recording your result and calculating the weight of 1 c.c. of water as before. Average the results. The average so obtained represents the weight of 1 c.c. of water. It should be very close to 1 gram. How near can you get to this result?

Tabulate the results.

**Experiment 9.**—*To determine the volume of a solid, either regular or irregular, by weighing the volume of water displaced.*

*Apparatus Required:* Balance, set of gram weights, overflow vessel, irregular or regular solid, piece of thread, and beakers.

*Procedure:* Place a small beaker under the spout of the overflow vessel, and fill the overflow vessel with distilled water. Take care that the spout is sufficiently above the beaker that it may be removed without disturbing the overflow vessel. Allow the overflow to run from the spout into the beaker. Note if the level of the liquid inside the overflow vessel is exactly level with the spout. If it is not it must be adjusted. Remove the beaker and substitute for it a clean, dry, weighed beaker. Tie

the piece of thread around the given solid and carefully lower it into the overflow vessel. Be very careful to avoid splashing. Wait until the water has stopped flowing from the spout into the weighed beaker. Remove the beaker, being very careful not to jar the overflow vessel in any way. Weigh the beaker and its contents and subtract the weight of the empty beaker. Now since 1 cubic centimetre of water weighs 1 gram (experiment 8), the weight of the water in grams is the volume of the solid in cubic centimetres.

## Special Devices Used to Obtain Greater Accuracy in Measurement

**Accuracy in Specialized Measurement**

The human eye finds it difficult to read, with certainty, divisions on a scale much smaller than one sixty-fourth of an inch. Modern mechanism requires an accuracy of from one one-thousandth to one ten-thousandth of an inch. Scientific measurement quite often requires even greater precision than this. Many mechanical devices have been invented to give this required accuracy. Verniers and micrometers are two of the best known.

*Verniers*—The vernier is a contrivance for accurately measuring smaller portions of space than those into which a scale is subdivided. It can be applied to either straight or circular scales, which greatly adds to its usefulness. The vernier consists of a second, sliding scale, moveable by the side of the main or first scale. This sliding scale is divided into equal parts, which are either a very little longer or shorter than the subdivisions of the main scale. It is this small difference of space which we are able to measure.

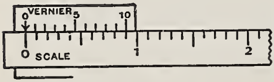


**Fig. 9.—Vernier Set at Zero**

Figure 9 represents a scale of inches subdivided into tenths, with a vernier scale beside it by which hundredths of an inch can be measured. This vernier

was made by marking off on it nine-tenths of an inch, and dividing that length into ten equal parts. Each division on the vernier is therefore equal to a tenth of nine-tenths of an inch. Consequently it is one hundredth of an inch shorter than one of the divisions of the original scale.

The first space of the vernier will therefore fall short of the first space of the scale by this one hundredth of an inch, and so on. If, then, the vernier be moved up by the side of the main scale so that the line on it marked "1" coincides with the line of the main scale which was just past it, we know that the vernier has moved one hundredth of an inch. Similarly if line "2" on the vernier comes to coincide with a line on the main scale, then the vernier must have moved two hundredths of an inch, and so on for all the other numbers of the vernier divisions. It will thus be seen that, before attempting to make a vernier measurement, it will be necessary to determine the value of one division of the vernier scale.

To do this, divide the value of the smallest division on the main scale by the number of the parts on the vernier. In Figure 10 the value of the smallest division on the main scale is one tenth of an inch and there are ten divisions on the vernier; therefore $\frac{1}{10} \div 10 = \frac{1}{10} \times \frac{1}{10} = \frac{1}{100}$ of an inch is the value of a vernier measurement.

*To read any vernier*—First, look at the zero line of the vernier. (This is often marked by an arrow head.)

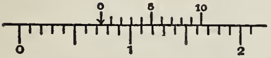


Fig. 10.—Vernier Set at 0.74

If it coincides with any division of the scale, that will be the correct reading and the vernier divisions are not needed. If, however, the zero line of the vernier comes between any two divisions of the scale, note the

next less division on the scale, and then look along the vernier till you come to some line of it which coincides with one of the divisions (no matter which) of the fixed scale. The number of this line on the vernier tells the number of the subdivisions of the vernier which are to be added to the reading of the entire divisions of the scale.

In Figure 10 the 0.7 division on the scale is the next less division to the zero line of the vernier. Looking along the vernier, we see that the fourth line on it coincides with a division on the main scale; we therefore add four one-hundredths to the .7 already noted. The reading is therefore 0.74 inches. Verniers such as the one described are used on surveyors' levelling rods, on barometers, and on callipers for use in machine shops. Curved verniers are to be found on surveyors' transits and high class protractors.

**The Micrometer**

The micrometer is a measuring device which makes use of the screw as a means of obtaining exceedingly fine measurement. Sir Joseph Whitworth, the eminent English mechanical engineer, constructed a measuring machine using this device, by which he was able to measure differences in length of one millionth part of an inch.

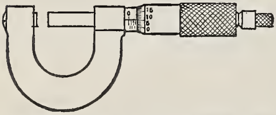


**Fig. 11.—A Micrometer Calliper which Measures to 0.001 of a Millimeter**

The micrometer is fitted to a large variety of instruments, for example, machinists' lathes, microscopes and spherometers. Its most familiar form is the machinist's micrometer calliper. This is a tool in common use in machine shops for measuring accurately the external dimensions of fine work. Figure 11 shows one of the commonest

forms of this useful tool. The use of the micrometer as a measuring instrument is based on the following principle. If a screw of known pitch be turned one revolution through its nut, the screw will have moved, in a straight line, a distance equal to the pitch of the thread. Also, if the screw be only rotated a fraction of a revolution, its linear motion will be the same fraction of the pitch of the thread. That is to say, if we had a bolt and nut with a thread of $\frac{1}{8}$ inch pitch, every time we turned the bolt head one complete revolution, the bolt would be moved $\frac{1}{8}$ inch towards or away from the nut, as the case may be. Or, if the bolt head was only turned $\frac{1}{4}$ of a revolution, then the bolt would move a distance equal to $\frac{1}{4}$ of $\frac{1}{8}$, or $\frac{1}{32}$ inch. Micrometers are usually made with 40 threads to the inch, that is $\frac{1}{40}$ inch pitch. The thimble of the micrometer corresponds to the head of the bolt. This thimble has a bevelled edge which is graduated into 25 equal parts. If, now, the thimble be rotated a distance equal to one of these parts, it follows from the principle given above that the end of the screw must have moved an amount equal to the pitch of the screw multiplied by the fraction of a complete rotation.

In this case $\frac{1}{40} \times \frac{1}{25}$ equals $\frac{1}{1000}$ of an inch.

*How to read a micrometer calliper*—

1. Read off the number of complete tenths exposed by the edge of the thimble. These are the first decimal place numbers.

2. Read off the last small divisions exposed beyond the last tenth. These small divisions are three in number and read respectively (a) .025, (b) .050, (c) .075. Write this number down, below the numbers read off in the first place.

3. Read off the number of the graduation on the

thimble which coincides with the axial line engraved on the barrel, and add as thousandths to the other two readings. Note that these thimble readings will always be between .000 and .025.

## QUESTIONS AND EXERCISES

1. What are the main difficulties encountered in actually making a measurement? Explain how they may be overcome.
2. Define "parallax" and show how it may cause grave errors in measurement, and how to eliminate such errors.
3. Describe in detail, telling the precautions you must observe at each step, how you would undertake to prove that the area of a circle is equal to 3.1416 times the radius squared.
4. By means of a diagram show how you would proceed to find the area of an irregularly bounded plane surface.
5. You are given an accurately turned wooden disc 3 inches in diameter. Describe how you would carry out experiments to show that $\pi$ has a numerical value of 3.1416.
6. Explain why, in making calculations from experimental data, it is always better to divide than multiply, if you have any choice.
7. Using a map of known scale, make a tracing of some irregular area on it, say a lake, and determine its area.
8. Why is the Metric system more suitable for the calculation of volume from measurement than the Brtish system?
9. What precautions must always be observed in reading the level of a liquid in graduates, burettes, and other similar measuring instruments?
10. How would you proceed to convert an ordinary tumbler into a graduate for measuring ounces of water?
11. You are given a quantity of fine shot. Outline the method by which you could find the volume of a single shot.
12. Explain how you would find:
    (a) The capacity of a small bottle.
    (b) The inside diameter of a narrow tube.
13. You are given a small cube of steel, an irregular mass of steel, a machinist's steel rule, and a balance and set of weights. How could you find the volume of the irregular mass of steel?
14. What devices are in common use for making measurements too small to be seen by the eye?
15. Explain the principle of the vernier.
16. Give the rules for determining the value of a vernier division and for reading a vernier measurement.
17. What is a micrometer? Explain the principle of making measurements with a micrometer.
18. Tell how to read a measurement made with a micrometer calliper graduated for thousandths of an inch.

# PART TWO

# AIR

## CHAPTER III

## THE EARTH'S ATMOSPHERE

**The Atmosphere**

Completely enveloping the earth is a vast ocean of air which we call the atmosphere. All our life is spent at the bottom of this great air envelope, much as the lives of certain creatures are spent at the bottom of the great water envelope, the sea. Although we live in this atmosphere, we cannot ordinarily see, taste, or feel the air. It is only when it offers resistance to rapid motion, or when the air itself is moving, that we notice its presence.

Comparatively few people have any true or definite ideas about the atmosphere, and still fewer persons realize its great importance to the earth. Before proceeding to any detailed study of the air, it will be well to obtain some definite ideas about the earth's atmosphere.

**The Height of the Atmosphere**

One of the most natural questions to ask regarding the atmosphere is, how far does it extend above us? The question cannot be answered with certainty, for, although there are several ways of obtaining an estimate of the height of the atmosphere, there are no means of accurately determining it.

From a careful study of twilight effects, from observations of meteors or "shooting stars", and by the evidence obtained from the *aurora borealis,* or "northern lights", astronomers inform us that the

atmosphere does not extend much beyond 100 miles above the surface of the earth.

**Protective Effects of the Atmosphere**

Two of the most important effects of the atmosphere are that it prevents the too rapid loss of heat into the outer spaces, and protects the earth against the incessant bombardment of meteors.

*The prevention of heat losses*—In this respect the atmosphere acts similarly to the glass of a green-house. It allows the rays of light and heat from the sun to pass freely through to the earth and warm the surface. As the earth becomes warm, it behaves like a steam radiator; it begins to give off dark heat rays. The dark rays cannot pass freely through the atmosphere, but are absorbed by it, thus making warm the layers of air near the surface of the earth. In this manner the atmosphere stores up the heat received from the sun and prevents it passing away into the intensely cold space around the earth. It acts as a blanket does in keeping one warm in bed during a cold winter's night.

*The protection against meteors*—It is not generally known that the world is constantly being bombarded from the heavens. Astronomers tell us that from ten to fifteen millions of meteors, or "shooting stars", enter the earth's atmosphere daily. So very, very many swiftly moving bodies, if they were to reach the earth's surface, would speedily make the existence of any form of life on the earth an impossibility.

Very luckily for us, the air makes an effective screen against this awful bombardment from the sky. Now and then, it is true, meteors do slip through, and a study of their effects enables us to realize dimly what conditions might be if the atmosphere were removed.

The protective effect is due to the terrific speed at which these meteors travel and the friction produced by them in passing through the air. If you drive a motor at fifty or sixty miles an hour, you may very soon become aware of the great resistance offered by the atmosphere. But sixty miles an hour is only a snail's pace compared with the speed of a meteor when it first enters the earth's atmosphere. The friction produced by the resistance of the air to this great speed causes the meteors to become quite hot, and they burn away into fine dust, chiefly oxide of iron, long before reaching the surface of the earth.

The common name for a meteor is a "shooting star". Really, it is no such thing. Were a real star to strike our earth, this planet would be almost instantly converted into a mass of brightly-glowing gas.

**The Atmosphere is the Great Carrier of Sounds**

Most of the sounds ordinarily heard by man and the animals are borne on waves in the atmosphere. Without an atmosphere, the earth would become absolutely silent; speech and music would be impossible.

In addition we must firmly grasp the following, which will become more apparent as we proceed with our study of the air. The atmosphere is the source of nearly all the food of plants and animals. All plants and animals are completely dependent upon the air. It is necessary for the production of fire, without which the lot of men would be little better than that of the animals. It gives us our weather and is the great transporter of rain and climate. Man uses the atmosphere in his work and play.

Finally, it must not be thought of as a dead, inert thing, for it is the home of countless myriads of tiny living organisms called germs, bacteria, and yeasts,

some of which are very useful to man; others scourge him with dreadful diseases; others ruin his crops.

## QUESTIONS

1. In what way does the earth's atmosphere afford protection against heat losses?
2. How are meteors prevented from reaching the surface of the earth?
3. What is the relation of the atmosphere to plants and animals?
4. How does sound travel?
5. Upon what evidence do astronomers base their statement as to the height of the atmosphere above the surface of the earth?

## CHAPTER IV

## THE PHYSICAL PROPERTIES OF AIR

**Matter and Non-Matter**

Going about our daily tasks, we become conscious of the existence of a great variety of things. One of the earliest lessons we learn is how to distinguish one of these from another. As we learn to observe more closely, we find that all things can be arranged into two great divisions which we term "matter" and "non-matter". *Matter* is anything which occupies space and has weight; *non-matter* cannot occupy space and has no weight, such as sound, light and heat.

**States of Matter**

Matter is known to us in three states, *solid, liquid,* and *gaseous.* Many substances, like coal and paper, are only found in the solid state; others, such as brass and solder, occur in two of the states; still others, for instance water, exist in all three states.

It is well known that ice, when heated, passes from the solid into the liquid state, and finally into the gaseous state. It is also well known that steam, when cooled, returns to the liquid state and finally to the solid state.

It is not generally known, however, that such substances as iron, copper, gold and silver, behave in the same manner under similar treatment. Most people have seen these substances only in the solid state, but many workmen, e.g., ironfounders and jewellers, are constantly using them in the liquid state.

With the aid of the spectroscope scientists have proved that in the fearfully hot atmosphere of the sun they exist as gases.

*Molecules*—Scientists, in studying the composition and behaviour of matter, have come to the conclusion that all substances are built up of extremely small particles which they call *molecules.* These molecules are so tiny that we cannot see even the largest of them through the most powerful microscope. How then can we be led to think that there are such things?

If a rose is taken into a room its perfume spreads to all parts of the room. Now this could hardly be possible, unless the tiny particles of the substance which gives the flower its pleasant smell had separated from the rose and penetrated to all parts of the room. This at once suggests that the sweet-smelling substance found in the rose is made up of separate particles, each possessing the rose smell.

*Molecules do not constantly touch each other*—Scientists believe that space exists between the molecules even in the hardest and densest forms of matter. Evidence can be found which suggests that this idea of spaces between the molecules is correct. For instance, if a small piece of a blueing compound used in the laundry be dropped into several gallons of water, the whole mass becomes tinged with the blue colour. Scientists explain this effect by saying that the molecules of the blueing compound have forced themselves between the molecules of water. This would not be possible unless there were spaces between the molecules of a substance.

*Molecules are in motion*—Scientists also tell us that in every kind of matter, even in the hardest and stiffest of solids, the tiny molecules are rapidly moving about. In solids, however, the molecules do not have any

tendency to fly apart, so that a solid always has a definite volume and permanent shape of its own.

The molecules of a liquid are moving faster and are more loosely held together than those of solids.

The molecules of a liquid, therefore, readily slip over each other. This slipping prevents a liquid from keeping a permanent shape of its own, but allows it to keep a definite volume.

In gases the molecules are so charged with energy that they travel with unbelievable speed in straight lines and show no tendency whatever to cling together, but are always trying to fly apart. This is what makes a gas spread to every part of the vessel in which it is held. It is the striking of these rapidly-moving molecules on the inside surfaces of a container that causes *gas pressure.*

*The Kinetic-Molecular Theory*—These ideas about the structure of matter are known as the *kinetic-molecular theory,* which simply means the "moving-particles theory". As more and more investigations are made, more evidences are found that agree with the theory. Up to date no evidence has been found that opposes it. All scientists, therefore, accept it as being a reasonable explanation of how matter is built up.

All material things are found to consist of substances. A tumbler is a material thing, because it occupies space, and has weight. It is made of the substance glass. Many other material things may be made of glass, for example, a bottle and a window pane. Glass, then, is a definite form of matter from which things are made. It is a substance. A door is a material thing; it is made of the substance wood. Many other things are made of this same substance, for example, chairs,

Substances

boxes and baseball bats. Wood, then, is a definite form of matter from which certain things are made. It is therefore a substance, but it is a quite different substance from glass. They differ because they possess different characteristics or properties.

**Properties**

Properties are those essential characteristics by which a substance may be recognized and distinguished from all other things. Every substance possesses two sets of properties: *physical properties* and *chemical properties.* If we wish to know about a substance we must ask, first, "What are its physical properties?" Second, "What are its chemical properties?"

By *physical properties* we mean those characteristics of a substance which are observed without the substance being changed into something else, e.g., colour, taste, smell, density, freezing point, melting point, elasticity, and the power of conducting heat and electricity. For example, copper is a red ductile metal; it is a good conductor of heat and electricity and has a density of 8.9. These properties can be observed without changing copper into another substance. They are therefore physical properties of the substance copper.

By the *chemical properties* we understand those characteristics of a substance which are observed only when the substance is changed into one or more other substances. For example, copper, when acted upon by moist air, is slowly converted into a greenish substance. It is also easily dissolved by nitric acid, producing a blue liquid and giving off brown fumes. These are chemical properties of the substance copper, since they only become apparent when copper is changed into another substance.

In studying any substance, its properties must be examined in order to ascertain:

1. What it looks like.
2. How it will behave.
3. What use we can make of it.

We shall now proceed to the study of air, attacking the problem on the lines given above.

The first question which arises is:

*Does air occupy space?*—We speak of an empty glass, an empty bottle, or an empty box. Are these things really empty or are they full of this invisible substance which we call air?

The best way to answer this question is to make air itself tell us. This is done by performing experiments.

**Experiment 10.**—*An experiment to determine if air occupies space.*

*Apparatus Required:* Glass tumbler, large glass jar filled with water.

*Procedure:* 1. Hold the tumbler with its mouth downward and force it into the water in the jar. Does the water enter the tumbler?

2. Release the pressure of your hand on the tumbler, but still support it in an upright position. Does the tumbler jump up again? Do you think there is something inside acting like a spring? What do you think it is?

3. Still holding the mouth of the tumbler under the water, tilt it a little until bubbles pass through the water. What are the bubbles? Does the water now enter the tumbler? Why?

*Observations:* Write out your observations in a connected paragraph.

*Deduction:* State your conclusion regarding the air and whether it occupies space.

Now, it is not wise to rely on one piece of evidence to prove a case, so one should try another experiment in order to confirm the findings of the first experiment.

**Experiment 11.**—*To confirm our conclusion that air occupies space.*

*What we want to prove:* That as long as air is not allowed to escape from a vessel, it will occupy space to the exclusion of all other substances.

*Apparatus Required:* A wide mouthed glass bottle equipped with a tightly-fitting, two-holed rubber stopper; a funnel with

a narrow tube; a short piece of glass tube bent at right angles; water.

*Procedure:* Set up the apparatus as shown in Figure 12. Place a finger over the open end of the glass tube. Pour water carefully into the funnel and notice that so long as you keep your finger on the open end of the tube, no water enters the bottle. Why? Take your finger away. The water now runs into the bottle and air escapes from the tube.

**Fig. 12. — The bottle contains air only, but the water will not run in until the finger is taken from the tube, and then the air can be felt coming out**

*Proof:* Hold a lighted match or candle near the open tube. The rush of air will bend the flame away from the tube.

*Conclusion:* Write out in a short paragraph the evidence gained above.

These and many other experiments which may be planned lead us to conclude that *air is a substance which occupies space.*

*Does air possess weight?*—It is really astonishing to find how many people there are who have no real opinion on this matter. There is no reason for any doubt since it can be so easily settled by performing the following simple experiment.

**Experiment 12.**—*To find if air possesses weight.*

*Apparatus Required:* Balance, two 500 c.c. Florence flasks, string, two single-holed rubber corks, short piece of glass tube, short piece of rubber tube and strong pinch-cock.

*Procedure:* Fit one of the flasks with a rubber stopper and glass and rubber tubing with pinch-cock attached (Figure 13). Fit the other with stopper alone. Suspend the flasks over the pans of the balance and, using sand or any other convenient material, balance them accurately. It is not necessary to know their weights since all we have to show is that by taking air out of one flask the balance is destroyed. Fit a glass mouthpiece into the rubber tube of the prepared flask. Avoid touching the flask with your hand. Now open the clip, and suck out some air. While

**Fig. 13.—When air is sucked out of the bottle, the bottle weighs less than before**

you are still sucking fasten the clip. Take out the mouthpiece and weigh again. The flasks wll no longer balance each other.

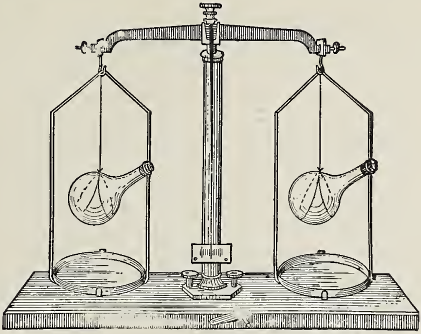


**Fig. 14.—Counterpoised Flasks**
When air is sucked out of one flask, this flask becomes lighter than the other.

Admit air by opening the clip and re-weigh. The flasks are now balanced again.

*Conclusion:* Because the extraction of air destroyed the balance by making the flask from which it was extracted lighter than the other one, we conclude that air possesses weight. This was proved when, by allowing the air to enter, the balance was restored.*

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**This experiment must be carefully performed or an incorrect result may easily be obtained. The above method has been selected since it does not require the use of an air pump. If the school possesses an air pump, then it should be used for this experiment as the greater quantity of air removed by the pump lessens the chances of error. The procedure when using an air pump would be:*

*1. Take the glass globe fitted with pinch-cock and pump connection. Open the pinch-cock and counterpoise the globe on the balance.*

*2. Remove the globe and screw into the plate of the air pump and exhaust the air. Close the pinch-cock and remove from the plate.*

*3. Place the globe on the balance and re-weigh. It will be seen that the globe is now lighter than before.*

*4. Open the pinch-cock letting the air enter. The balance is restored.*

At the beginning of the chapter it was stated that matter was anything which occupied space and had weight. The experiments described above conclusively prove that air has both these properties. Therefore it is a material substance.

**Is Air a Material Substance?**

It has been demonstrated that air has weight, and you have been told that air extends for at least 100 miles above the surface of the earth. It is to be expected, therefore, that this mass of air will bear down upon the surface of the earth, exerting pressure upon it and upon objects at or near the earth's surface. Ordinarily we are not conscious of the existence of this pressure, but it is quite easy to show that it is present and that it is considerable. One of the easiest and most striking ways of showing the existence and great amount of this pressure is by performing the following experiment.

**Air Exerts Pressure**

**Experiment 13.**—*To demonstrate that air exerts pressure and that this pressure is very strong.*

*Apparatus Required:* An empty gallon (oil, varnish, or kerosene) can fitted with a screw cap, or with a good, well-fitting cork, some water, and a source of heat.

*Procedure:* Place about 2 inches of water in the can and get it boiling vigorously. After steam has issued from the opening for a minute or two, replace the stopper and immediately remove the can from the source of heat. Screw the cap tightly down (or push the cork tightly into the hole). Allow it to cool and note what happens.

*Observation:* As cooling takes place the can is crushed out of shape.

*Explanation:* The steam from the boiling water expelled the air from the can and occupied its place. On sealing the opening the heated steam was completely filling the can. As the steam cooled, it occupied less and less space, so that at last there was nothing inside the can to oppose the pressure of the air outside it. The walls of the can were not strong enough to support this pressure, and so the can crumpled up.

A few years ago, a large steel oil tank belonging to a railway company in the United States was similarly crushed into a shapeless heap of scrap metal. The railway company had occasion to transport a large quantity of molasses in bulk. The yard master ordered one of these oil tanks to be blown out with live steam to remove the oil smell. As the job was not completed at the end of the day, the man doing the work conceived the idea of leaving it full of hot steam all night. So he closed the outlet valve of the tank and shut off the steam. In the morning the tank car was in ruins. The steam had condensed, leaving a vacuum inside the tank, and the pressure of the atmosphere did the rest. No one was more surprised at the result than the workman.

Another simple experiment provides a striking demonstration of the great pressure exerted by the air.

**Experiment 14.**—*To demonstrate the pressure of the atmosphere by using its force to hold down a piece of wood while we break it.*

*Apparatus Required:* A piece of wood 2 ft. long, 4 inches wide, and ¼ inch thick. A newspaper, a piece of broom handle, or other hard stick, and a table with a smooth top, large enough to allow the paper to be spread out on it without overhanging.

*Procedure:* Place the board on the table so that about six inches of it project beyond the table. Open the newspaper to its fullest extent and lay it over the board, watching that no part of it overhangs the table and that it is smoothed out as flatly as possible. Strike the projecting end of the board a sudden, heavy blow with the broom handle.

*Observation:* The projecting end may break off but the part under the paper will not move.

*Explanation:* This surprising result is due to the pressure of the atmosphere. The use of the paper is to provide enough surface for the atmosphere to press upon. This pressure is not noticed by us under ordinary circumstances, because it works equally in all directions. When, however, the pressure of the air is removed from one side of a body, it is felt with great force on the other side. (Recall the last experiment.) Now when the projecting end was suddenly struck, the air had not time to rush in between the table and the newspaper and so give an upward pressure equal to that of the downward pres-

sure. The result was that the board was held firmly on the table. That this is true can be proved by setting up the experiment once more, but instead of striking a sudden sharp blow, gently press on the projecting end of the board with your finger. The board is now easily raised and pushed off the table, because the paper rises slowly and allows the air to rush in between it and the table top. Since the upward pressure on the under side of the paper is the same as the downward air pressure on the upper side of the paper, we have only the weight of the board and the paper to move.

If an air pump is available the pressure exerted by the air may be demonstrated by the following additional experiments.

1. Remove the screw from the exhaust tube in the centre of the pump plate. Place the bell jar on the plate over the hole. Note that the bell jar may be quite easily lifted up and down. Replace the bell jar and operate the pump handle. Now try to remove the jar. It cannot be moved. Next unscrew the relief plug and let the air enter the bell jar. Try to lift the jar now. It is easily moved once more. Write out an explanation of this experiment.

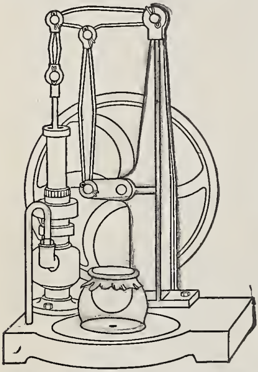

Fig. 15.—Pressure of the Air Breaking a Membrane

2. Tie a sheet of thin rubber over one end of a palm, or bladder, glass and place it over the opening in the plate of an air pump. Make one or two strokes with the pump handle. The rubber will be pushed inside the glass. Why? See Figure 15.

3. Take the glass globe fitted with a stop-cock and screw connection which you used in determining the weight of air. Open the stop-cock and place the opening in a jar of water. Observe that no water enters the globe. Next screw the globe in the opening of the air pump, leaving the stop-cock open, and operate the pump. Then close the stop-cock. Insert mouth down in the water once more and open the stop-cock. Note how the water now rushes into the globe and continues doing so until it is nearly filled with water. Write out an explanation of this experiment.

**The Famous Magdeburg Experiment**

The air pump was invented about 1650 by Otto Von Guericke, and one of his most interesting experiments was that with his famous *Magde-*

Fig. 16.—The Experiment with the Magdeburg Hemispheres Performed by Otto Von Guericke in 1650 A.D., before the German Emperor

*burg Hemispheres,* performed before the German Emperor in 1650 A.D.

Von Guericke made two hollow hemispheres about 22 inches in diameter. These were fitted so well together that he was able to pump out the air from between them. The pressure of the surrounding atmosphere then held them firmly together. In the test before the Emperor and the Reichstag at Magdeburg it required sixteen horses, eight pulling on each hemisphere, to pull them apart. Figure 16 is a picture taken from an old book, showing how this experiment was carried out.

**Does the Atmosphere Exert Pressure Equally in all Directions?**

It has already been stated that the upward and downward pressure of the atmosphere are equal at any point. Are the pressures exerted in a horizontal direction equal to each other and to the up and down pressures?

**Experiment 15.**—*To prove that the pressure exerted by the atmosphere in all directions is equal at any given point.*

*Apparatus:* A thistle tube with a large head, a sheet of rubber, soft string, rubber tube and pinch-cock.

*Procedure:* Cut the stem of the thistle tube to about 4 inches in length. Stretch the rubber tightly over the head of the thistle tube and tie firmly in place. Slip the rubber tube over the stem and adjust the pinch-cock. Now place the end of the tube in the mouth, open the pinch-cock and suck some of the air out of the tube. While still sucking, close the pinch-cock. Hold the head of the tube in turn downwards, upwards, and to the right and left sides.

One very important difference between all gases and liquids is that gases may be made to occupy less

**Compressibility and Expansibility of Air**

space without altering their weight, simply by increasing the pressure upon them, but the same treatment produces no effect on the volume and weight of a liquid. This behaviour of gases under pressure is known as *compressibility.*

There are three ways by which a gas may be compressed:

1. By the exertion of an outside pressure.
2. By forcing more gas into the container.
3. By cooling the gas.

**Experiment 16.**—*To show that when the outside pressure on a given mass of gas is increased its volume diminishes.*

*Apparatus:* A long test tube, a tall jar filled with water, a retort stand and clamp.

*Procedure:* 1. Place the test tube mouth downward in the clamp of the retort stand, so that its rim is just below the surface of the water in the tall jar. Measure the length of the air column in the tube and note it down.

2. Push the test tube several inches further under the water. This increases the pressure on the air in the tube. Clamp into place. Measure the air column again and compare it with the last measurement.

*Observation:* 1. The length of the column of air is shorter in the second position than in the first position.

2. The diameter of the tube remains unchanged.

3. The outside pressure in the second position is greater than in the first.

*Conclusion:* The volume of air in the second position is smaller than that in the first position, while the pressure on it is greater. Therefore, an increase of outside pressure is seen to cause a decrease in volume.

*Is there any relation between the pressure exerted on a given mass of gas and its volume?*—The fact that air could be compressed by outside pressure was known to the early Greek philosophers, but it remained for Robert Boyle, an Irishman, and one of the cleverest of the seventeenth century scientists, to discover that there is a definite relation between the pressure and volume of a given weight of air. Boyle expressed his discovery in the following law, which is known to scientists as *Boyle's Law. The volume of a given mass of a gas varies inversely as the pressure applied.*

**Experiment 17.**—*To verify Boyle's Law experimentally.*

Since Boyle's Law states that the volume varies inversely as the pressure applied, it is necessary to show that if we double

the pressure on any given mass of gas, its volume will shrink to one half the original volume.

*Apparatus:* A Boyle's Law tube apparatus and sufficient mercury to fill the tube.

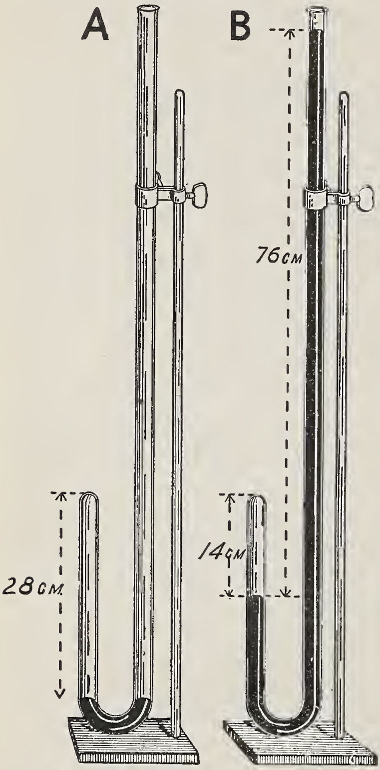


Fig. 17.—Apparatus Used to Verify Boyle's Law

*Description of Apparatus:* The Boyle's Law tube is made of strong glass bent into a J shape. The shorter branch is closed and the longer one open. The apparatus is mounted on a board, fixed in an upright position. Behind the two branches of the tube are scales, by means of which the height of the mercury in them can be read.

*Procedure:* 1. Pour sufficient mercury in the open end of the tube to fill the curved part of the J and bring the level of the mercury to the same level in each branch as in A, Figure 17. When this condition has been obtained the pressure of the air on the surface of the mercury in the long tube is exactly equal to the pressure of the trapped air in the shorter tube; that is, pressure of one atmosphere. Note the length of the air column in the closed branch.

2. Pour mercury in the open end of the tube until the column of air in the closed branch is half the original volume.

3. Measure the height of the mercury in the long branch above the level of that in the shorter branch, as in B. It will be nearly 76 cm.

*Explanation:* A height of 76 cm. of mercury is equal to a pressure of one atmosphere at sea level, and as we have added this equivalent of one atmosphere to the weight or pressure of the atmosphere always present, there is a pressure equal to two atmospheres pressing on the enclosed air. Hence, by doubling the pressure the volume is halved.

Examples of compressing air by forcing more gas into the container are very familiar to us in the inflation of tires, toy balloons, air pillows and footballs.

That cooling air results in a compression, or loss of volume, is made familiar to us by the fact that bicycle or auto tires are softer in the early morning than in the middle of the day. Every boy knows that he should not pump his cycle tires too tightly in the early morning as the air occupies less space then.

**Expansibility of Air**

Air, in common with all other gases, is always striving to occupy more room. No matter how much space a gas is occupying, it can always occupy more room if it has the opportunity. This power of unlimited expansion is a distinguishing characteristic of gases. Many of our everyday experiences illustrate this; for example, the rush of the air out of a punctured tire, the spreading of cooking odours all through the house, and the forcing of a fine spray of liquid from an atomiser.

The expansion of gas may be brought about in three ways:

1. By removing the pressure.

2. By removing a portion of the gas from the container, provided the walls of the container are rigid.

3. By heating the gas.

The following experiments illustrate the expansibility of air.

**Experiment 18.**—*To show that air expands when the external pressure on it is reduced.*

*Apparatus:* A glass bottle having a capacity of about one quart. A well fitting cork bored with one hole. A length of glass tubing drawn to a jet at one end. This tube must be long enough to reach to the bottom of the bottle and project several inches above the cork.

*Procedure:* Pass the tube through the cork. Half fill the bottle with water, insert the cork and tube, taking care that the jet is outside the bottle. Now blow down the tube and note the bubbles of air passing through the water. What happens to them? Continue blowing steadily for a little time. Remove the tube from the mouth, and note that the water is now forced out of the bottle several inches above the top of the jet. How do you account for this?

Write a short explanation of what has happened.

**Experiment 19.**—*To show the expansibility of air on reducing the external pressure upon it.*

*Apparatus:* Air pump, bell jar, toy balloon.

*Procedure:* Partially inflate the balloon, tying firmly so that no air can leak out. Place under the bell jar of the air pump and exhaust the air from the jar. The balloon now swells up.

On readmitting the air to the bell jar the balloon will gradually shrink back to its original size.

Write out an explanation of what you observed.

That removing some of the air from a container having rigid walls will cause the remainder of the air to expand, is not readily shown by a simple experiment. It may, however, be deduced from the action of the air pump, which makes use of this fact in exhausting the air from a vessel connected with it. The pump operates as follows: When the piston is raised, the air from the vessel $R$ expands into the cylinder $C$ through the valve $A$; when the piston descends, it compresses this air and closes the valve $A$, opening the exhaust valve $B$. On

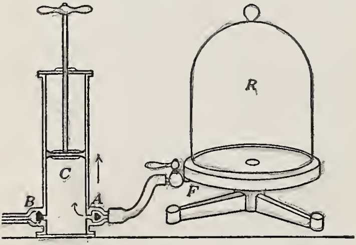


**Fig. 18.—A Simple Vacuum Pump and Receiver**

raising the piston for the next stroke, the air remaining in the vessel expands again into the cylinder and the cycle of operations is repeated. Thus it will be seen that at each double stroke a certain fraction of the air is removed from the vessel, and the remaining air expands to take its place. This continues until this expansive force of the air is not strong enough to lift the valve so that it can pass out of the vessel.

That heat causes the air to expand is very easy to show by several simple experiments.

**Experiment 20.**—*To show that heat will cause air to expand.*

*Apparatus:* A Florence flask fitted with a cork through which is passed a short length of glass tube; spirit lamp or Bunsen burner, a large beaker, or sealer, full of water.

*Procedure:* Hold the Florence flask so that the mouth of the glass tube is underneath the water in the beaker or sealer. Warm the flask carefully with the spirit lamp or Bunsen burner. Observe the escaping bubbles passing through the water. Note also that the water does not rise into the flask, which shows that the heat has caused the enclosed air in the flask to expand. If, now, the source of heat be removed and the flask allowed to cool, the water will rise into the flask. This shows conclusively that heat causes air to expand.

**Fig. 18a.—A Gas Expands When Heated**

The ready compressibility and expansibility of air give it the power of returning promptly to its original condition after receiving a shock. This is a very important characteristic of air and is called its *elasticity* or *resiliency*.

*Elasticity* is a very useful property possessed by many kinds of matter, but none of them display it to such a degree as do the gases. Elasticity may be defined as that property which enables a body to recover readily its original condition after being subjected to some stress or strain. We make use of the elasticity of air in pneumatic tires and footballs.

Buoyancy is a very important property of air. By it we understand the lifting effect exerted by the upward pressure of the air on everything surrounded by it.

**Buoyancy of the Air**

If an object is completely surrounded by air it must be displacing an amount of air equal to its own volume. Now the buoyant force or lifting effect of the air on such an object would be equal to the weight of this displaced air. If the body is lighter than the weight of the air it displaces, it will rise in the air in somewhat the same manner as a cork, suddenly let free under water, will rise to the surface. The use of balloons and airships depends upon the buoyancy of the air.

**Experiment 21.**—*To demonstrate the lifting effect or buoyancy of the air.*

*Apparatus:* Air pump, bell jar, and baroscope.

*Description of Apparatus:* The baroscope is an instrument consisting of a hollow metal or glass globe, suspended at one end of a small balance beam and counterpoised by a small weight at the other end.

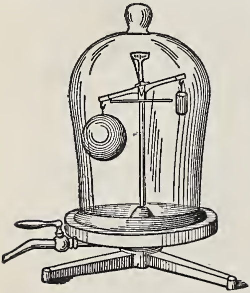

Fig. 18b.—Lifting Effect of Air Depends on the Volume of Air Displaced

*Procedure:* Place the baroscope on the plate of the air pump, and adjust the small weight until the pointer shows that the globe and weight are balanced. Cover with the bell jar and exhaust the air. The globe will be seen to sink. Let the air back, and the balance is restored again.

*Explanation:* Now the change in balance occurs only when the air is removed. It is evident, therefore, that the air must have been supporting the globe to a greater extent than it supported the weight. It was able to do this because the globe displaced more air than the weight. Therefore the lifting effect on it was greater than on the small heavy weight.

## QUESTIONS

1. How is matter distinguished from non-matter?

2. Explain the difference between the physical and the chemical properties of a substance.

3. How can a gas exert pressure on the walls of anything in which it is confined?

4. What are molecules? State some reasons for believing in their existence.

5. What are the essential characteristics of (a) Solids, (b) Liquids, (c) Gases?

6. Would you say that air is matter or non-matter? Give the reasons for your answer.

7. How does the inflation of a bicycle tire illustrate the compressibility of the air?

8. What is meant by the term *elasticity?*

9. State Boyle's Law and describe an experimental proof of the law.

10. Why is it difficult to fill a narrow-necked bottle if a tightly fitting funnel is used?

11. Why is it not advisable to pump bicycle or automobile tires too hard in the hot weather?

## CHAPTER V

# HOW MAN USES THE PHYSICAL PROPERTIES OF AIR

The last chapter was devoted to the examination of air in order to learn something about its physical properties. As a result of this study, it has been shown that air is a material substance, and as such possesses the properties of occupying space and having weight. In addition to these general properties possessed by all material substances, it has been learned that:

1. Air can exert pressure and that it does so with equal force in all directions at any given point.
2. Air is very easily compressed.
3. Air is expansible.
4. Air can be set in motion.

In the present chapter certain devices will be studied with a view to finding out how man has applied these properties to assist him in his work and play.

Almost everyone is familiar with a football, and most people are aware that compressed air is necessary to give the ball its proper bounce. What makes the ball bounce? What makes the ball bounce or spring up into the air after hitting the ground, or rebound from the kicker's foot? It is common knowledge that, if the football is in a slack condition, it makes accurate work in the game an impossibility. Also a slack ball demands much more effort on the part of the players, tiring them out before the end of the game.

**The Football**

Now the tightness of the football depends upon the effort of the compressed air inside the bladder to escape from its imprisonment. The correct degree of tightness is obtained by forcing a sufficient quantity of air into the bladder of the ball and retaining it there. The greater the quantity of air forced into the space provided by the leather cover of the football, the greater becomes the internal effort of the imprisoned air to break out of its confinement. Hence the cover of the ball is stretched very tightly, producing the effect of stiffness.

*The bounce of the ball* is due to the fact that, when the compressed air inside the ball receives a sudden shock, it is compressed still further. The effect of this extra compression is to produce a flattened area at the point where the shock is received. The air inside the ball quickly expands again, and forces the flattened area back into its original shape. This spring-back of the ball into shape again is what throws the ball away from any object which provides the sudden shock—the boot, the ground, the fence post.

Thus it will be clear that footballs and tennis balls are devices by which man uses three distinct physical properties of air:

1. Its property of occupying space.
2. Its ease of compressibility.
3. Its great elasticity.

**Experiment 22.**—*To show that unless a body possesses the power of recovering its shape after receiving a shock, it cannot bounce.*

*Apparatus:* A rubber ball, a hardwood ball, a brass ball, and a ball of putty, plasticene, or well-kneaded clay; a slab of stone or iron.

*Procedure:* Smear the surface of the slab with oil or ink. Carefully lay each of the balls on the slab and then pick them up. Examine the size of the spot of ink or oil picked up by them. Next throw the rubber ball down on the slab and catch it on the rebound. Examine the size of the spot produced both

on the ball and on the slab. Do the same with all the balls except the putty, plasticene, or clay one. It will be observed that the spots produced are much larger than the spot they produced when simply laid on the slab. Now take the putty, plasticene, or clay ball and throw it down upon the slab. It does not bounce, but remains in a flattened condition on the slab.

*Explanation:* Rubber, hardwood, and brass are all elastic substances. After being pushed out of shape when they struck the slab, they at once sprang back, producing the rebound. Clay, plasticene, and putty, not being able to recover their shape, were not able to rebound. The fact that the balls which rebounded flattened and then recovered their shape is shown by the fact that the spots made by them when thrown on the slab were much larger than the spots made when they were simply placed on it.

**The Pneumatic Tire**

The pneumatic tire is a device by which air is used to lessen the shocks given to rapidly moving vehicles passing over the uneven surfaces of roads. The invention of the pneumatic tire has been responsible for the success of two methods of quick transportation in modern times. These are the safety bicycle and the automobile. It is quite safe to say that without the pneumatic tire the bicycle could never have become a success as a means of transport. The success of the automobile is as much due to the pneumatic tire as to any mechanical engineering device or skill. No engine could be constructed light enough, yet sufficiently strong, to operate over ordinary roads and withstand the hard usage if it were mounted on any other wheel. The pneumatic tire utilizes the following characteristics of air:

1. Its power of exerting pressure in all directions. By this property it prevents the rim of the wheel from meeting the surface of the road.

2. The ready compressibility of air. This enables a tire to be inflated by a simple pumping device which, if necessary, may be operated by hand.

3. The great elastic power of the air. This enables a vehicle equipped with pneumatic tires to pass over

the bumps in a road with a minimum of shock and vibration.

**The Air Gun**

The air gun is a device which utilizes the easy compressibility and expansibility of air in order to fire a bullet. It has the advantage of silence, smokelessness and the absence of flash. Its great disadvantage is due to the difficulty of obtaining a sufficient compression of air

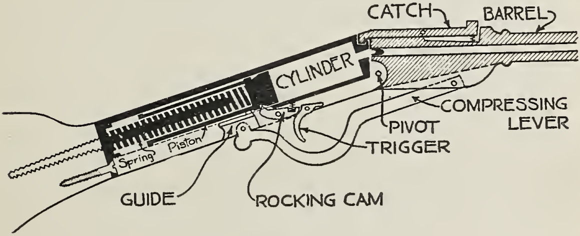


Fig. 19

by simple means, and thus its range is very short. In one of the simpler types, the air is condensed in a chamber above the barrel by means of a syringe in the stock. On pulling the trigger, a valve between the air chamber and the barrel is opened. The sudden expansion of the compressed air forces the bullet to a distance of from 60 to 80 yards. See Figure 19.

**Air Pumps**

Any apparatus for removing air from, or forcing air into, a given space by mechanical means is an air pump. Those which force air into a container are called *air compressors,* and those which remove air are termed *vacuum pumps.* In general construction, the pumps are similar, the main difference being in the action of the valves. Either pump may be converted into the other kind by reversing the valve action. Both types

make use of the compressibility and the expansibility of air, but the vacuum pump mainly uses the expansibility of air, and the compressor utilizes the property of compressibility.

**The Vacuum Pump**

The operation of this type of air pump has already been described on page 44. One of its best known applications is in the vacuum cleaner. It is also used to exhaust air from incandescent lamp bulbs, and X-ray tubes. Another application of the vacuum pump is found in the pneumatic tube system seen in some departmental stores for carrying cash from the counters to the cashier's office. In many cities pneumatic tubes are used for carrying telegrams from branch offices to the main despatching station, as in London, England. The cash or telegram to be carried is placed in a leather case which fits in the metal tubes of the system, and is propelled through them by the air currents produced through the action of a vacuum pump. Vacuum pumps are also used in factories where sugar is refined, milk condensed, and fruit juices concentrated, in order to cause rapid evaporation at temperatures lower than those at which these substances would burn. Otherwise they would be unpleasant to the taste. They are also used in chemical and physical laboratories.

**Air Compressors**

The common football inflator and bicycle pump are examples of simple and portable air compressors. Another form in which they are familiar to us is the pumping device on the gasoline blow torches used by the plumbers, and on the Primus or wickless oil stove. In these forms of the air compressor, we find a cylinder and piston with a concave leather disc on its under side. On the up-stroke of the piston the air

leaks in around the loosely fitting leather disc and so fills the cylinder. On the down-stroke the air, being pushed closer and closer together, tries to escape back around the piston, but in so doing lifts the sides of the concave leather disc. This makes the disc fit closely against the sides of the cylinder, thus preventing the air from escaping. As the piston travels further into the cylinder, it compresses the air until it has force enough to open a valve. This allows it to enter the tire in the case of a bicycle or auto, and the fuel tank in the case of a blow torch or Primus stove.

*Large air compressors* are operated by power, usually steam, gasoline, or electricity. They generally have a tank which acts as a storage reservoir. Some types have an automatic arrangement which starts the pump when the pressure in the storage tank drops below a certain point, and stops the pump whenever a certain high pressure is reached.

*Uses of compressed air*—These are many and varied. Some of the most common and most useful applications are:

1. To operate the brakes on railroad trains and street cars. The railways, also, use compressed air to operate signals.
2. For whistles on street cars and electric trains.
3. In mining and tunnelling, both to operate the drilling machines and to run underground locomotives for carrying coal and ores from the working faces to the shafts.
4. In bridge-building and the erection of structural steel frameworks, to operate a variety of small tools such as pneumatic rivetting hammers and chisels.
5. In the pneumatic shield, a device which enables man to drive tunnels under the beds of rivers, or through water-logged strata.

6. To enable men to work in caissons and diving bells far below the surface of the water, in order to lay the foundations for bridge piers and dock walls.

**The Pneumatic Caisson**

The pneumatic caisson is a device utilizing compressed air, to enable construction to be carried on under water which is too deep to allow the use of other methods.

It is principally employed in the building of bridges or lighthouses. The pneumatic caisson consists of a steel cylinder furnished with a hard steel cutting edge at the bottom. Some seven or eight feet above this cutting edge an air-tight steel floor is built right across the tube. This forms an air-tight space called the working chamber. Above this floor, a second steel tube is constructed of smaller diameter than the first, so as to provide a double wall. The space between the the walls is filled with concrete, providing great strength and weight to the structure. Near the top of the cylinder, two other chambers are formed by three more air-tight floors across the cylinder. The working chamber is joined to these upper ones by means of strong steel tubes of quite large diameter. There are generally three tubes, one of which is used by the men in passing to and from the working chamber. Another is used to transfer materials to the chamber or to remove the excavated material. The third is used to circulate air constantly by means of air pumps in one of the upper chambers. This circulation is necessary to keep the air pure enough for the men to breathe, and to maintain sufficient pressure to hold back the water, sand, and mud from rushing in and filling the chamber. The important part of a pneumatic caisson is the air lock. This is a device which enables men and materials to

pass in or out of the working chamber without changing its air pressure. The air lock is formed by the floors in the upper part of the cylinder.

To leave the caisson, the workman climbs up the ladder in the man-way tube and opens a door which leads into the lowest of the upper chambers. This is the air lock. This door is then shut, and a valve connecting the air lock with the outer air is opened. This allows the compressed air in the lock to escape until the pressure within the lock and the outer atmosphere is equal. The door leading out of the lock to the next floor can now be opened, and the man climbs up the ladder into the top chamber, from which he can, at any time, pass out of the caisson. To enter the caisson, this process is reversed. Material is hoisted out or lowered into the caisson in the same manner down the tube set apart for the purpose.

As the earth is removed, the caisson sinks until the solid rock is reached. The entire caisson is then filled with solid concrete and forms part of the foundations of the bridge, or whatever is being built. Figure 20 shows the inside of a caisson.

*The lift pump* is a device by which air is removed from a tube, and a column of water is pushed into its place by the pressure of the atmosphere on the surface of the water in which the tube is inserted. It is the usual form of pump used for raising water out of wells. The common opinion is that the pump sucks up the water into the tube. Hence, these pumps are often called *suction pumps.* This idea is quite wrong. It is the pressure of the atmosphere which pushes the water into the tube. You can easily prove that suction cannot raise water into a tube.

**Experiment 23.**—*To demonstrate that it is atmospheric pressure and not suction which lifts liquids into a tube.*

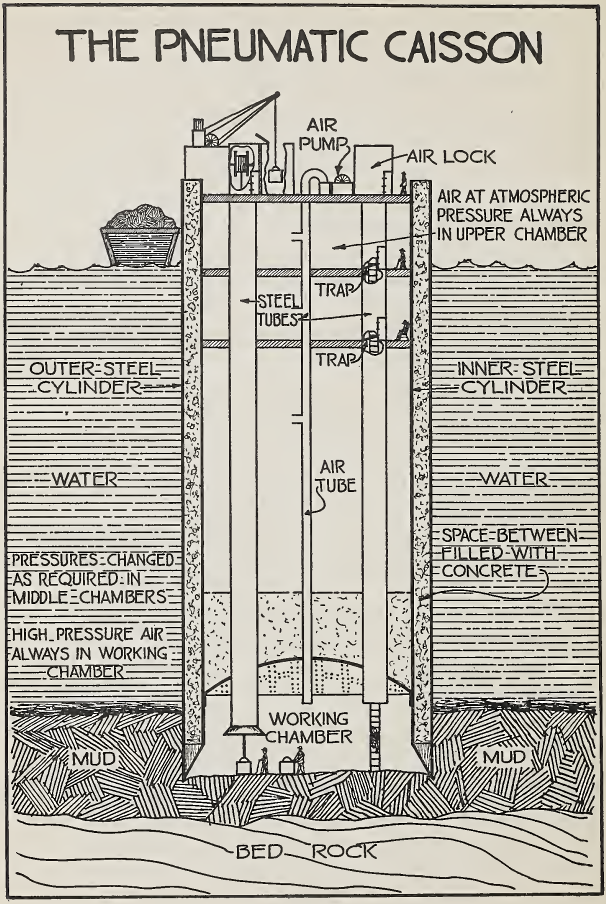
THE PNEUMATIC CAISSON
AIR PUMP
AIR LOCK
AIR AT ATMOSPHERIC PRESSURE ALWAYS IN UPPER CHAMBER
TRAP
STEEL TUBES
TRAP
OUTER STEEL CYLINDER
INNER STEEL CYLINDER
AIR TUBE
WATER
WATER
SPACE BETWEEN FILLED WITH CONCRETE
PRESSURES CHANGED AS REQUIRED IN MIDDLE CHAMBERS
HIGH PRESSURE AIR ALWAYS IN WORKING CHAMBER
WORKING CHAMBER
MUD
MUD
BED ROCK

Fig. 20

*Apparatus:* A bottle fitted with a well-fitting rubber stopper through which is inserted a short length of glass tubing.

*Procedure:* 1. Fill the bottle right to the lip with water. Carefully insert the stopper, being careful not to trap any air inside the bottle. Now suck at the tube. You will find that, suck as you may, no water will come out of the bottle.

2. Remove the stopper and pour out a little of the water. Replace the stopper. Note that air is now inside the bottle above the water. Suck at the tube now. Water is freely drawn out of the bottle.

*Conclusion:* Because water could only be lifted out of the bottle when air was already inside, we are forced to the conclusion that air must be the lifting agent which forces the water up the tube.

**The Lift Pump**

The ordinary lift pump consists of a cylinder *C* which is connected with the well by the pipe *T*. Working up and down inside this cylinder, is a piston *P* which is operated by the handle. There are two valves, one *V*, fitted in the piston, which can only open upwards. The other valve *S* is at the bottom of the cylinder and is hinged so that it works like a trap door; it can only open upwards. On the up-stroke of the piston, the valve *V* in the piston remains closed because of its weight and the weight of the water and air above it. Therefore, it lifts out the air and water above its upper surface. This causes a partial vacuum between the lower surface of the piston and the bottom of the cylinder. But the pressure of the air on the water in the well forces some water up through the pipe *T* opening the valve *S* and entering the cylinder *C*. On the down-stroke of the piston, the valve *S* closes, and valve *V* opens, allowing the water to pass above

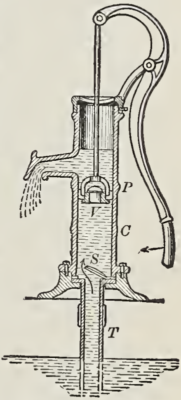

**Fig. 21.—A Lift, or "Suction", Pump**

the piston. On the next up stroke, this water above the piston is lifted out through the spout, and the operations above described are repeated. Because this pump is worked by atmospheric pressure, the valve *S* must never be more than 34 feet above the surface of the water in the well. In actual working, they are usually placed not more than 30 feet above the surface of the water. This limit is imposed because atmospheric pressure is unable to support a column of water higher than 34 feet. Why this is so will be seen in the next chapter.

**The Siphon**

The siphon is a device for transferring liquids from a higher to a lower level, over an intervening elevation. It consists of a length of piping open at both ends, bent into the shape of a J or L. To use a siphon, the piping is filled with the liquid to be moved. This is done by suction, or otherwise if more convenient. When the tube is quite full, the ends are closed and the shorter end inserted below the surface of the liquid to be moved. The longer end is arranged so that its opening is below the level of this liquid. If the ends are now opened, the liquid will flow through the tube until it is all completely transferred, or until the level of the liquid is the same at both ends of the tube.

**Explanation of the Action of a Siphon**

Consider Figure 22, which shows a siphon arranged to transfer the liquid from the vessel *A*, over its side, into the vessel *D*, placed at a lower level. *A A′* is the level of the liquid in the higher vessel, and *D D′*, the level in the lower one. If the tube be filled with the liquid, flow from *A* to *D* commences. What causes this flow? Look at the diagram again. The air pressure on the surface of the liquid

in *A* may be considered as equal to the air pressure on the surface of the liquid *D*. But the vertical height of the liquid at *D* is greater than the vertical height at *A* by an amount equal to the distance from *C* to *D*. Therefore, there is a greater weight of liquid in the longer leg of the tube. It is this extra weight which supplies the force that moves the liquid. This can be shown by using a rubber tube for the siphon and raising the lower vessel *D* to such a position that the level of the liquid in it is at the same height as the level of the liquid in *A* when the flow will cease. This is evidently due to the disappearance of the extra liquid in the longer leg. If the vessel *D* be slowly lowered, then the flow will commence again, gaining in speed as the length *C D* becomes longer.

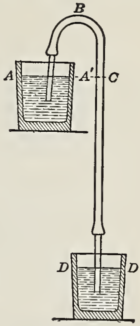


**Fig. 22.—A Siphon**

A siphon, therefore, will work as long as the free surfaces of the liquids are of different heights. The direction of flow will always be from the higher surface level to the lower one. It must also be remembered that the flow of liquid will cease if the bend of the siphon is too high above the surface of the higher body of liquid. This height depends on the density of the liquid to be transferred. In the case of water, 34 feet is the vertical limit of the height of the bend at sea level. At higher altitudes this limit will of course be less. Lighter liquids than water can be lifted higher

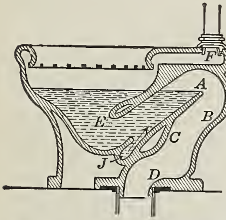


**Fig. 23.—Cross Section of a Jet-siphon Water Closet**

in direct proportion to the relation between their densities and that of water. Similarly, heavier liquids than water cannot be lifted as high as 34 feet.

**Use of Siphons**

Siphons have many uses. They are found in all houses, used as traps under sinks, wash bowls and water closets to draw the wastes rapidly down the soil pipes, and to leave a water seal in an inverted siphon so that the sewer gases do not enter the dwellings. They are also used to draw liquids from vessels not provided with vents, and which cannot be tipped. Sometimes they are used to draw off clear liquid from vessels without disturbing a sediment at the bottom. Engineers often use siphons on a large scale for carrying water in aqueducts over hills. Sometimes they turn them upside down and use them to carry irrigation canals or aqueducts

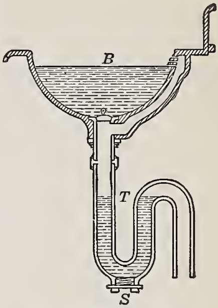


**Fig. 24.—Wash Bowl and S-trap**

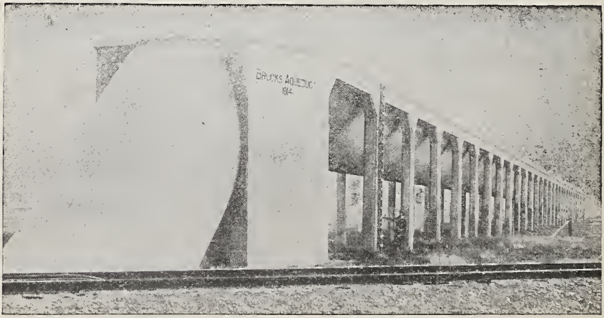

**Fig. 25.—Brooks Inverted Siphon, Alberta**

under roads, railroads or canals. This form is called an inverted siphon. There is a good example of an inverted siphon on the C. P. R. irrigation canal near Brooks, Alberta. See Fig. 25.

**The Vacuum Cleaner**

The name "Vacuum Cleaner" is an unfortunate term, since it leaves the impression that the vacuum does the cleaning. This is quite a wrong idea about vacuum cleaners. A vacuum, as ordinarily produced, is simply a pressure lower than the atmospheric pressure. It is produced by pumping air out of a closed space. If an opening be made into such a space, air will rush in and destroy the vacuum. A vacuum cannot lift the tiniest speck of dust. It is the *current of air that rushes into the vacuum, carrying the dust along with it, that does the cleaning*. A vacuum cleaner, then, is a device which cleans by air currents. These air currents are set up by the establishment of a partial vacuum produced by a rapidly rotating centrifugal fan. In the portable form, the motive power is usually

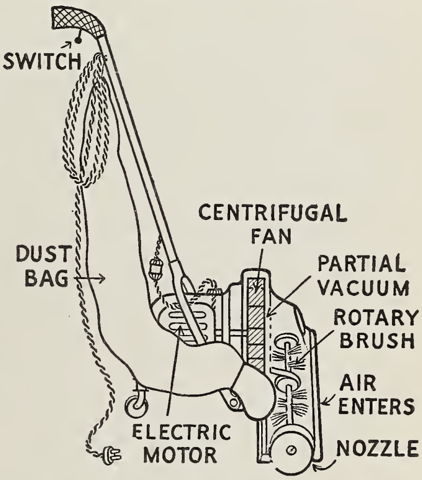


**Fig. 26.—Study the diagram. It shows the parts of an electric vacuum cleaner**

electricity, but in some large, fixed installations, steam or internal combustion engines are often used to supply the power. The operation of the vacuum cleaner is as follows. The electric motor turns a metal fan at a high speed. The action of the fan is to drive the air towards the outer end of the fan blades, thus producing a partial vacuum at the centre of the fan. The atmospheric pressure outside the machine forces the air into this partial vacuum. This air can only enter through the slit in the nozzle of the machine. It rushes through this slit with great speed, carrying the dust and dirt with it. This dust-laden air passes through the fan case into a closely-woven cloth bag. The bag balloons out, and the air escapes through the meshes of the cloth, but the dust is retained. The electric motor, also, rotates a small brush which beats on the carpet, thus helping to loosen the dirt. As the machine is moved back and forth over the carpet, the air pressure lifts the carpet a little and holds it close to the nozzle, so that most of the air passes through the fabric. This lifting action also brings the carpet into the path of the revolving brush.

**The Windmill**

Windmills are machines by which man uses the energy of the winds to generate power, to operate pumps, to grind grain and to saw firewood. In the past windmills were very important generators of power, but to-day they are relatively unimportant. They attained their greatest importance in Holland and in the Fen District of England, where they were used to operate pumps to drain the low-lying land reclaimed from the sea. In Canada, windmills are chiefly employed on farms to pump water. Even in this service they are being displaced by the gasoline motor. Essentially, the windmill consists of:

1. A wheel of suitable size, built up of specially shaped blades set at a suitable angle so as to use as much as possible of the wind's energy.

2. A rudder or vane, which, when set in a certain position, holds the above wheel in the most favourable position to catch the full force of the wind. If set in another position, the wheel is turned away from the wind and ceases to rotate.

3. A tower, sometimes of stone or wood, but usually of steel, whose function it is to raise the wheel in the air in order to get the greatest advantage from the wind.

4. A system of gears by which the rotary motion of the wheel is changed into an up-and-down motion which operates the plunger of the pump.

Windmills have the advantage of cheapness in operation; there are no fuel bills to pay. Their mechanism is simple, so that expert attention is not required. The great disadvantages of windmills are due to the variability of the winds. This variability often results in power not always being available when required. Then again, winds vary greatly in strength; this, too, affects the power output of a windmill, making it unsteady.

**The Balloon**

The balloon is an apparatus by which man employs the buoyancy of the atmosphere in order to travel through the air. A balloon is a large, but light, gas-tight bag, filled with some gas lighter than air. This bag is covered with a rope net from which is suspended a light car or basket. The gases are very inflammable and sometimes ignite, causing dreadful disasters. Recently, balloons have been filled with helium, a gas that will not take fire. Helium is one of the gases found in the mixture issuing from some natural gas

wells in Canada and the United States. At present, it is expensive, and its supply limited. Some balloons are filled with heated air, notably those which are used for balloon ascensions at fairs and circuses. Owing to the rapidity with which it cools, heated air cannot be used for long trips, nor can balloons filled with it rise to any great heights. A balloon will continue to rise as long as its weight is less than the weight of the air which it displaces. When these become equal, the balloon simply floats at a constant height. A balloon is not fully inflated to start with, because, as it ascends, the outside pressure of the atmosphere on it becomes less and the gas inside it expands. If the balloon were fully inflated at the ground, this expansion would become sufficient to burst the envelope. Balloons cannot be guided through the air; they are carried about in the direction of any current of air which they meet. The only control a balloonist can exert is that over its rise and fall. This he does by adjusting the weight of the balloon to the buoyancy of the air. When desiring to ascend, he throws out ballast, which is carried in the form of sandbags. When he wishes to descend, he allows gas to escape through a valve, thus decreasing the buoyancy.

The first successful balloon ascent was made at Paris, on June 5th, 1783, by the brothers Montgolfier. They used a balloon 110 feet in circumference, inflated with heated air. The highest balloon ascent was made in 1901 by Berson and Suring, two German aeronauts, at Berlin. They ascended to a height of 35,000 feet (nearly 7 miles). The longest balloon flight was made on March 24th, 1913, by Rumpelmayer, who made a flight of 1,493 miles from Paris to the vicinity of Kharkoff in Russia.

Ordinary balloons possess the means neither of propulsion nor of guidance. This deficiency lays them under serious disadvantage as a means of travel. Ever since the first successful balloon flight in 1783 inventors have been at work trying to remedy this deficiency. Many devices were tried, some of which now seem absurd. Blanchard, the English aeronaut, tried to use oars and a rudder, but failed. Another inventor sought to propel the balloon by making a large hole in the side of the balloon, through which the rush of escaping gas was, by reaction, to force the balloon forward. These, and all other early devices, failed, principally because of the spherical shape of the balloon, which presented too great an area to the wind.

**Airships**

It was only when the shape was changed that control over direction was achieved. In 1852, Henri Giffard, a Frenchman, equipped a cigar-shaped balloon with a very light steam engine and succeeded in attaining a speed of almost seven miles an hour. This was the first airship.

The great forward step was accomplished in 1898 when Santos-Dumont, a Brazilian resident of Paris, took the gasoline engine of one of his motor-cycles and fitted it to a balloon of his own design. On the first flight made with this small airship, Santos-Dumont proved that it was under control, although, in descending, the machine was wrecked, and the young inventor nearly killed.

In 1901, he won the Deutch prize offered for a flight from St. Cloud round the Eiffel Tower, and back, a distance of nearly seven miles, to be completed within thirty minutes. To Santos-Dumont must be given the credit of applying the gasoline engine to the balloon. In 1898, also, Count Zeppelin began his career as a

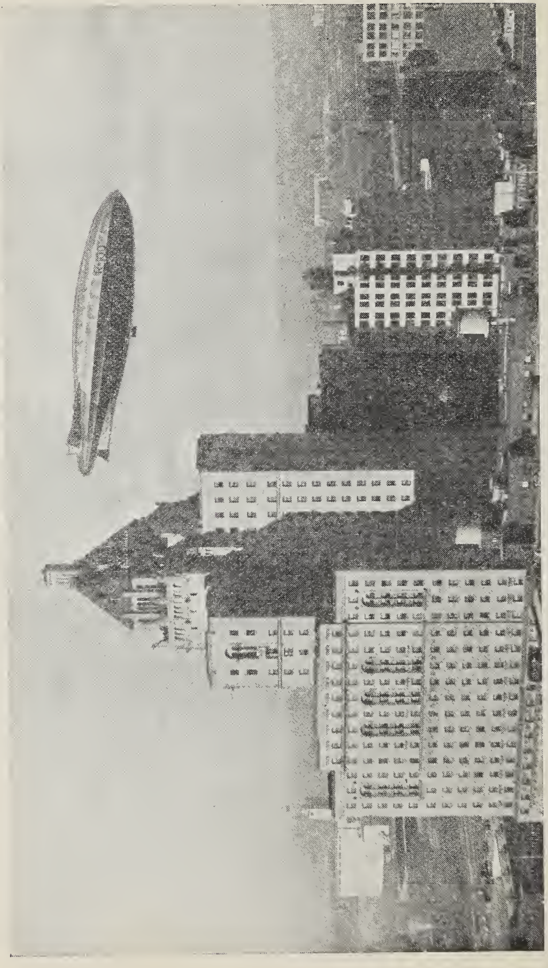

**Fig. 27.—The British airship R-100 over Toronto, 1930**

builder of airships in Germany. His first airship was built and ready for trials in 1900. It was the biggest and the most powerful airship that had been built up to that time.

Zeppelin firmly established the supremacy of the rigid type of airship over all existing types of lighter-than-air craft. All the great modern airships like the British R 34, which flew across the Atlantic in 1919, and the United States Shenandoah, which was so unfortunately wrecked in 1925, are built on the Zeppelin plan.

Airships, then, are dirigible balloons provided with propellers and gasoline engines, and with horizontal and vertical rudders. They are shaped like huge cigars, with a pointed nose and tail, so as to reduce the resistance as they pass through the air. They usually have a lattice girder framework made of very light but strong aluminum alloy, and are covered with a light weather-proof fabric. The gas bags which form the balloon part proper of the airship are separate bags filled with either hydrogen or helium gas. Each bag is in a separate compartment of the frame. There are from 15 to 20 such bags in a big airship.

Airships and aeroplanes must not be confused. They operate on entirely different principles. The airship is a lighter-than-air machine and relies on the buoyancy of the atmosphere to raise it, only using its engines to propel it along. The aeroplane is a heavier-than-air machine and depends upon its engines both to lift and to propel it.

## QUESTIONS

1. Explain how three different properties of air are illustrated in the use of a football.

2. Discuss the statement "The success of the automobile is as much due to the pneumatic tire as to any mechanical engineering device or skill".

3. What are (a) the advantages, (b) the disadvantages of an air gun?

4. What is the difference between an air-compressor and a vacuum pump? State three uses of each.

5. Write, in your own words, a description of the pneumatic caisson and point out its uses.

6. State three physical characteristics of air. Explain how each is applied in some useful way.

7. Upon what characteristics of air does the operation of each of the following depend: (a) automobile tire, (b) balloon, (c) vacuum cleaner?

8. What is a siphon? Name three common uses of siphons found in a house.

9. What is the essential difference between a balloon and an airship? In which way are they similar?

10. Why does a tennis ball lose much of its bounce if it becomes punctured?

11. Draw diagrams of a lift pump, to show the position of the piston and valve (a) at the first down-stroke, (b) at the first up-stroke. Using your diagram, write an explanation telling how these pumps raise the water.

12. Explain the action of a siphon. Would it be possible to use a "U" tube with limbs of equal length as a siphon?

13. Mention some mechanical uses of compressed air.

14. What is the use of the small hole in the lid of a tea pot?

## CHAPTER VI

## MEASURING THE PRESSURE OF THE ATMOSPHERE

**The Duke of Tuscany's Pumps**

In 1630 the Grand Duke of Tuscany had a well, about 40 feet deep, dug on one of his estates near Florence. A pump was installed, but, to the Duke's surprise and disappointment, it was found impossible to pump the water. The pump was of the best workmanship, and it actually raised the water to a height of 33 feet. Yet all the efforts of the workmen failed to make it rise any higher. The Duke was greatly puzzled, so he asked his friend Galileo if he could explain the peculiar behaviour of the pump Now, long before, Aristotle, the great thinker of ancient Greece, had taught that "Nature abhors a vacuum", and people thought that this was the reason why a pump lifted water out of a well. According to this theory the water should have risen to any height, so long as there was a vacuum above it. Galileo was just as puzzled as the Duke in the matter. He had never before heard of a pump behaving in this manner; he remarked that evidently Nature's abhorrence of a vacuum did not extend beyond thirty-three feet. This remark of Galileo did not explain anything, but it set him thinking. Why was thirty-three feet the limit of Nature's abhorrence?

Soon after this incident Galileo got into trouble on account of his opinions and teachings. He was sum-

moned to Rome, tried, and sentenced to imprisonment for life at the discretion of the Pope. This Pope was friendly to Galileo and interpreted the sentence very mildly. The close imprisonment lasted for four days only, after which he was exiled to the Archbishop's Palace at Siena. Some years after, Galileo was allowed to visit his daughter as she lay dying at Arcetri. She died a few days later. Galileo then requested to be permitted to return to Florence. This request was refused, but he was allowed to live on at Arcetri with his own son as gaoler. No visitors were allowed, but he was able to work and study. Five years before he died the poor old man was stricken with total blindness. Broken in health and blind as he was, the authorities evidently thought that Galileo had been sufficiently punished, for he was now permitted to receive visitors. The most eminent people of Europe came to visit him, among them the poet Milton. All were delighted to find that his wonderful powers of conversation and his charm of manner were unimpaired by his sufferings and infirmities. Among those who came was Evangelisti Torricelli, who stayed with the grand old man during the last three months. During their many discussions Galileo told Torricelli about the Duke of Tuscany's pumps, and suggested that Torricelli might solve the problem which had evaded him. The problem interested Torricelli, and in 1643 he performed the experiment which definitely proved that it is the pressure of the atmosphere which raises water in pumps, and not the suction of the pump.

This experiment was also a most important one for science, since it swept away the false principle *"Nature abhors a vacuum"* which had ruled the minds of men for nearly 2000 years.

## Torricelli's Experiment and the Invention of the Barometer

After thinking the matter over carefully, Torricelli became convinced that, as the atmosphere possessed weight, it must be able to exert pressure on all surfaces exposed to the air. He therefore concluded that the reason why the water could not rise higher than thirty-three feet in the pump, was because the pressure caused by the weight of the atmosphere was not strong enough to lift it any higher. The next step was to prove this reasoning by experiment. About this time Torricelli had come into the possession of a large quantity of mercury. In studying this substance he noticed that it was nearly 14 times heavier than water. So he said, "If it is really the air balancing a column of water 33 feet high, then it will balance a column of mercury one-fourteenth of the height."

**The Argument**

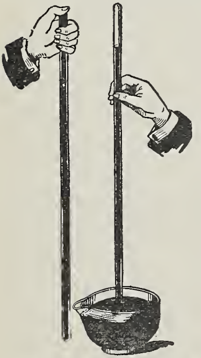

**Fig. 28.—Torricelli's Experiment**
Balancing the pressure of the air with a mercury column.

A strong glass tube, about three feet long, was sealed at one end and filled with mercury. The open end was closed with the thumb, and the tube inverted, so that this open end was beneath the surface of some mercury in a basin. On removing the thumb, the mercury fell to a height of about 30 inches above the level of the mercury in the basin. This agreed with Torricelli's expectations. (The space above the mercury in the tube is the most perfect vacuum we know how to make, and is known as the *Torricellian vacuum.*)

**The Experiment**

In this manner Torricelli was able to measure the pressure exerted by the atmosphere. He had invented a new and strange form of weighing machine, to which Robert Boyle some twenty-five years later applied the Greek name *Barometer, or Weight Measurer.*

Torricelli also noticed that the height of the mercury in his tube varied slightly, and that these variations were connected with the changes in the weather. He thus foreshadowed one of the main uses to which we put barometers.

**The Proof**

About this time there lived in France a very brilliant young man, by name Blaise Pascal. Hearing about Torricelli's experiment, Pascal was struck with its simplicity and the new ideas which it suggested about the air. He obtained some glass tubes, repeated the experiment for himself, and was convinced that Torricelli was correct in thinking that it must be the pressure of the atmosphere that supported the column of mercury in the tube. Most people, however, scoffed at the idea.

"Why," they said to Torricelli, "the pressure of the mercury column amounts to 15 pounds to the square inch."

Torricelli agreed that they were right.

"Then," they said, "you must be wrong, because, if that were the case, we should not be alive to argue about this matter at all, for the pressure on a man's body would amount to several tons."

Torricelli could not deny that it looked absurd, but, as far as he could see, there was no other explanation. Pascal, therefore, set to work to devise a means of testing Torricelli's explanation. He thought if he could, in some manner, reduce the air pressure on the surface of the mercury in the basin, he would then be

able to see whether the mercury stood at the same height as before.

Pascal reasoned now that, as the air had weight and extended far above the earth's surface, its pressure should diminish as one ascended, say, a high tower or a mountain.

There are no high hills or mountains at Rouen, where Pascal lived, so he thought of the tower of one of the churches. He carried his tube to the top of the tower and found, on measuring the height of the mercury there, that it was slightly less than it had been at the bottom of the tower. Still the difference was not large enough to make sure, for such small differences had been observed before, in connection with weather changes. Pascal then remembered that his brother-in-law, Perier, lived in Auvergne, which was a mountainous district, so he wrote to him asking that he carry out a test. Perier consented and carried out the instructions which Pascal had sent. In company with some friends, Perier climbed the Puy-de-Dome. On reaching the top, they filled a tube with mercury and inverted it in the usual manner. On making measurements, they found the mercury column to be about three inches shorter at the top of the mountain than it was at the foot. The test proved that Torricelli had been correct in his explanation, and it also showed a new use for the new instrument, namely, that it could be used to measure altitude or height above sea level. Thus the barometer was invented, and a new and valuable instrument was placed in the hands of scientists.

**Experiment 24.**—*To make a simple barometer.*

*Apparatus:* A strong glass tube about 3 feet long and from a quarter to a half inch in diameter, a basin of mercury, a burette or retort stand, and a yard or metre stick.

*Procedure:* Carefully clean and dry the tube. Seal one end by heating carefully in a flame. When cool fill the tube with

mercury, adding a little at a time and being careful not to form any air bubbles. Carefully close the open end with a thumb or forefinger, and invert the tube so as to immerse the open end under the mercury in the basin. Be very careful not to remove the thumb or finger until the mouth of the tube is well under the mercury in the basin. On removing the finger, the mercury will sink in the tube, rising and falling a few times in the tube before finally coming to rest, somewhere about 30 inches above the surface of the mercury in the basin. Clamp the tube in a vertical position in the stand. This is a simple barometer. If a small piece of gummed paper is stuck on the tube at the level of the mercury, and the column observed over several days, it will be seen that the mercury slowly rises and falls. These changes in the height of the column of the mercury we know, from what has been said before, to be due to the changes in the pressure of the atmosphere. To measure the pressure of the atmosphere at any time, place the yard or metre stick against the tube and measure the distance between the surfaces of the mercury in the basin and in the tube.

## How to Calculate the Pressure of the Atmosphere from this Experiment

The usual way of expressing the pressure of the atmosphere is by stating the height of the column in a mercury barometer. Barometers are therefore usually graduated in inches or centimetres. This method of graduation, however, does not tell us what is the actual pressure being exerted by the atmosphere. To find this actual pressure in pounds per square inch, or in grams per square centimetre, it is necessary to make a simple calculation. This calculation is based upon the fact that 1 cubic inch of mercury weighs .49 pounds and 1 cubic centimetre weighs 13.6 grams. To change inches of mercury pressure to pounds per square inch we multiply the barometer reading by .49 if the barometer is graduated in inches, or by 13.6 if it is graduated in centimetres.

*Example*—If the barometer reads 28 inches, what is the pressure of the atmosphere?

*Solution*—28 × .49 equals 13.72 pounds per square inch.

If the barometer reads 70 cm., what is the atmospheric pressure?

$70 \times 13.6$ equals 952 g. per sq. cm.

The average pressure of the atmosphere at sea level is equal to the pressure exerted by a column of mercury 30 inches high. Therefore, by the rule given above, $30 \times .49$ equals 14.7 pounds per square inch. Therefore, 14.7 pounds per square inch is called 1 atmospheric pressure; 2 atmospheric pressures would equal twice the quantity or 29.4 pounds per square inch, and so on.

**What is Meant by the Term One Atmospheric Pressure?**

For the metric system of graduating barometers, 76 centimetres is the average height of the barometer at sea level, so $76 \times 13.6$ or 1033.6 grams per square centimetre is called one atmospheric pressure, when using the metric system of weights and measures. For most general calculations the pressure of 1 atmosphere is usually taken to be 15 pounds per square inch or 1 kilogram per square centimetre.

## Forms of Barometers

There are two forms of barometers in common use, namely, the mercurial barometer, and the aneroid barometer. Each has its own peculiar advantages and disadvantages.

**Mercurial Barometers**

Mercurial barometers are essentially Torricellian tubes. They are of two main types, the cistern type and the siphon type. In scientific laboratories and meteorological observing stations the cistern type is the kind more often used; the siphon type is most commonly found in houses.

*The Cistern Type*—In this type of barometer the pressure is determined by reading the height of a column so constructed and mounted that these readings may be made accurately and conveniently. Figs. 29 and 30 show the standard form of this type of barometer. The complete instrument is shown in Fig. 29. It consists of a long glass tube enclosed within a brass protection tube. The top of this glass tube is sealed and the lower end constricted and then drawn out almost to a point.

Fig. 29.—Fortin's Barometer

The lower end reaches down into the mercury contained in a well or cistern. Fig. 30 shows a vertical cross section of this cistern and its internal arrangements. It has a flexible leather bottom which can be moved up or down by turning the screw at the bottom. It is necessary to adjust the level of the mercury to a fixed zero point from which the instrument is graduated. This zero point is indicated by the tip of an ivory pin fixed at the top of the cistern. The pin can be seen in the upper right-hand corner of the cistern in Fig. 30. It is also indicated by the letter P in the drawing of the complete instrument.

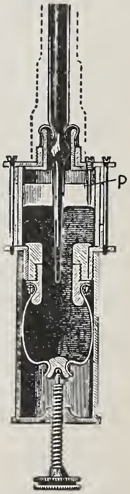

Fig. 30.—Reservoir of Fortin's Barometer

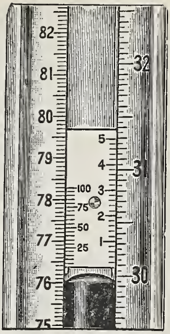

Fig. 31.—Barometer Scales and Verniers

Before making the reading, the adjusting screw must be turned up or down so as to bring the surface of the mercury to the tip of the pin. The height of the column is then read directly from the scale S, Fig. 29, which is engraved on the brass case of the instrument. This scale is fitted with a vernier attachment operated by the screw B to obtain readings as small as $\frac{1}{100}$ of an inch. Fig. 31 shows the usual scale and vernier attachment fitted to these bar-

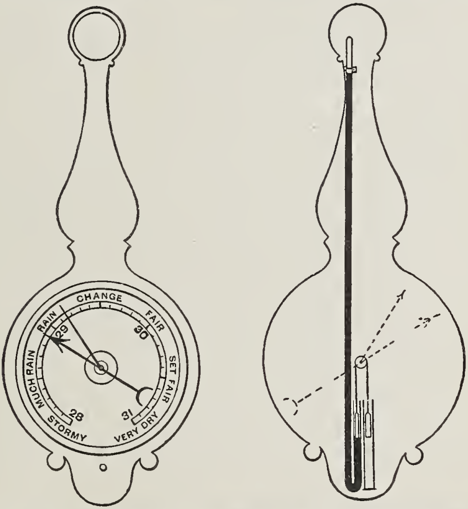

Fig. 32.—Front and Back of a Barometer or Weather Glass Used to Show Changes in the Pressure of Air, and therefore Changes of Weather

ometers. Note that one side of the scale is graduated in inches and the other in centimetres.

*The Siphon Type*—These are made with J tubes. The long end is sealed, and the short one left open. A float is inserted in the open end and is allowed to rest on the exposed mercury surface. This float rises or falls as the mercury level in the instrument changes. Its motion is transferred to a wheel by a silk string, one end of which is fastened to the float, while the other end, after passing around the wheel, is fastened to a counterbalance weight. The weight rises or falls and thus turns the wheel which is fastened to a pointer. This pointer moves over a dial plate graduated in inches. Siphon barometers are not accurate but are often seen in houses and are popularly called "Weather Glasses". Fig. 32 shows the front and back view of one of these siphon barometers.

**The Aneroid Barometer**

The aneroid barometer contains no liquid, the varying pressures of the atmosphere being shown by the changes produced on the cover of an airtight metal box. Fig. 33 shows an aneroid barometer with its outer protecting case removed, and also a diagram to illustrate the principle of the operation.

From the study of this diagram an aneroid barometer will be seen to consist of an airtight metal box having a corrugated top, called the vacuum box in the diagram. From this box most of the air has been removed, so that the pressure inside the box is less than the atmospheric pressure outside it.

The cover of the box is flexible and is pressed inward when the air pressure outside increases. When the air pressure is decreased, this cover moves outward. These changes are very slight. Fastened to the top of the box is a post holding a knife-edge. This

knife-edge moves up and down with the changes of the box cover. The knife-edge is kept continually touching a rod by the action of the main spring, seen to the right of the diagram. This rod is connected to a chain of levers seen to the left of the diagram.

The levers magnify the motion of the box cover, and, by means of the fine chain, transfer the motion to a

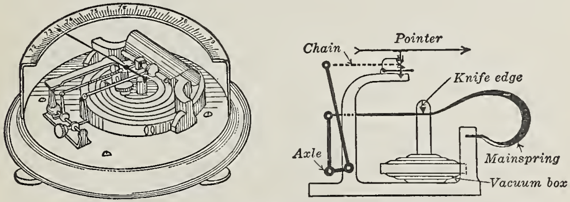


**Fig. 33.—Aneroid Barometer with Diagram to Show its Principles**

wheel to which is fitted a spring and a pointer. The spring keeps the chain at a constant tension. The pointer measures the amount of motion on a circular scale placed underneath it, this scale being graduated by comparison with a mercury barometer. Modern aneroids are not quite so accurate as a mercury barometer, but they are much more sensitive; that is, they make their changes faster than the mercury barometer. Aneroids are also much more convenient to carry about, because they are much more compact and may be carried in any position, since they have no liquid to spill out. They also have the advantage of lightness. Since they are so portable and quick in their action, aneroids are much used by geologists and surveyors in measuring altitudes, in preference to the awkward, heavy and slower-acting mercury barometers. Because they are so often used in this way,

most aneroids are engraved with an altitude scale in addition to the inches of mercury scale.

Mercurial barometers have the advantage of great accuracy; therefore they are always preferred for use in scientific laboratories or in places where they can remain in a fixed position, as, for example, in meteorological stations.

**Self-recording Barometers**

Self-recording barometers or barographs are compound aneroid barometers, equipped with a pen attached to a pointer, and a device for rotating a chart by means of a clock mechanism. As the pressure changes, the pen moves up and down, tracing its course on the rotating cylinder of paper. They

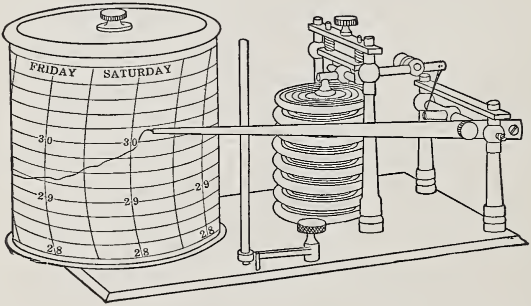


Fig. 34.—Self-recording Barometer

are usually arranged to give a continuous record of the pressure for a week, without changing the paper. In some meteorological stations, as in Toronto, the mercurial barometers are made self-recording by the attachment of a mechanism which prints the height of the mercury on photographic paper.

## Uses of the Barometer

The four principal uses of the barometer are:

1. To determine altitude.
2. To foretell weather changes.
3. To warn coal miners of dangerous explosive conditions in the mine.
4. To measure gas pressure.

**Determination of Altitude by Barometers**

We have previously seen that, when we ascend through the atmosphere, the amount of air above is reduced. In consequence, the pressure exerted by the air as we ascend will support shorter and shorter columns of mercury. Since the barometer readings thus vary with the position of the barometer, it is clear that these alterations provide a ready means of telling the elevation of any place above sea level, provided we know the rate at which the barometer readings vary with the alteration in elevation. These alterations in pressure cannot be easily determined by any simple rules, on account of many interfering conditions which are themselves of a very changeable nature. They are therefore obtained from tables which give the average pressures for the different elevations. In the absence of such tables, we may take it as a general rule for approximate work that the barometric pressure decreases by one inch for each 900 to 1,000 feet of elevation up to an altitude of one mile.

**Weather Changes Indicated by Barometers**

The accurate forecasting of weather changes is a very intricate business, requiring great skill and a large number of observations of many different conditions. One of the principal instruments used by the weather forecasters is the barometer. The following simple rules will

enable one to anticipate, intelligently, weather changes from day to day:

1. A slow but steady rise of the barometer indicates fair weather.

2. A slow but steady fall indicates unsettled or wet weather (snow in winter).

3. A rapid rise indicates clear weather with high winds.

4. A very slow fall from a high point usually predicts wet and unpleasant weather without much wind.

5. A sudden fall indicates a sudden shower or high winds, or both.

6. A stationary barometer indicates a continuance of the existing conditions. Slight tapping on the barometer face will sometimes move the hand a little, indicating whether the tendency is to rise or to fall.

In coal mines where explosive gases are generated, the barometer is an instrument of great value. These dangerous gases escape from the coal. The rate at which they escape varies with the pressure of the atmosphere on the face of the coal seams. When the atmospheric pressure is heavy, that is, when the barometer is reading high, the gases escape less quickly than when the pressure is low. Now a drop of one inch in the air pressure means a reduction of .49 of a pound on every square inch of coal surface exposed in the mine. Hence, when the barometer is low, the mixture of these gases and air in the mine may quickly reach the danger point, unless steps are taken to counteract the change. In many gaseous mines, aneroid barometers, because they record the changes of pressure more quickly, are installed at convenient places. The instruments are read and recorded three times each day. The person in charge of the mine is

**Uses of a Barometer in Mines**

notified of decreases of pressure, and is thus informed of the impending danger.

**Measuring the Pressure of a Gas**

Measuring the pressure of a gas is usually accomplished by means of a glass tube bent into the form of a U, and containing mercury. One side of the tube is connected with the gas container and the other left open to the atmosphere. The mercury will be observed to change level. The difference of level between mercury surfaces in the U-tube indicates the difference between the pressure inside the container and the atmospheric pressure outside. If the mercury assumes a higher level in the side attached to the container, then the gas has a lower pressure than the atmosphere outside. Similarly, if the mercury rises higher in the tube open to the air, then the gas has a higher pressure than the atmosphere. In the first case, we subtract the difference in level from the barometric reading at that time, and in the second case we add it to the barometric reading.

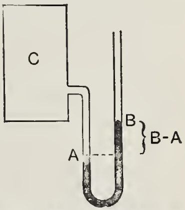


**Fig. 35. — Measurement of Gas Pressure**

## QUESTIONS

1. Why could the water from the Duke of Tuscany's well only rise in his pumps to a height of 33 ft.?

2. How may the air be made to support a column of liquid? What will be the most marked difference between two columns so held up if one be of water and the other of mercury?

3. By the aid of a diagram show how you could construct a drinking trough for poultry from a quart sealer and a shallow pan. Give an explanation of its action.

4. How did Torricelli manage to measure the pressure of the atmosphere?

5. Describe in detail the construction of a simple barometer. Give three uses of the instrument.

6. If the barometer reads 30 inches, what is the atmospheric pressure? If the barometer reads 68 cm., what is the atmospheric pressure?

7. What kind of weather may be expected if the barometer shows (a) a gradual fall from a high point, (b) a sudden rise, (c) a steady pressure for several days.

8. Of what value are barometric observations to the coal miner?

9. How can you measure the pressure of the gas in a gas main?

10. If, when drinking lemonade through a straw, a pip sticks in the end, the straw flattens. Why?

11. If some boiling water be placed in a stone-ware bottle and a cork inserted at once, it is found difficult to pull out the cork after the water has cooled. Why?

12. Explain the principle of the Aneroid Barometer.

# CHAPTER VII

## TEMPERATURE CHANGES IN THE ATMOSPHERE AND THE AIR MOVEMENTS CAUSED BY THEM

The last chapter was devoted mainly to a discussion of how atmospheric pressure was discovered and the manner in which it is measured. For the sake of simplicity the pressure changes due to the heating and cooling of the atmosphere were not considered. These effects must now be studied, for they are of the greatest importance.

Many of our common experiences indicate to us that if air is heated it expands. For example, most people know that a bicycle tire, which was only fairly hard in the morning, is often much harder by noon. Again, if a tire be tightly inflated and left in the direct sunshine on a hot day, it very often bursts, owing to the expansion caused by the heating of the air contained within it. But, as we have seen, notions obtained from our common experiences may be mistaken ones. We should, therefore, test such notions, by experiment if possible, before finally accepting them as correct.

**Experiment 25.**—*To find out what happens when air is heated and then cooled.*

*Apparatus:* A glass flask with a long narrow neck, a jar of water, and a spirit lamp.

*Procedure:* Support the flask neck downward in the jar of water, so that the mouth is an inch or so below the surface of the water. Note that the water does not enter the flask. Why? Now place both hands firmly on the globe of the flask and note that bubbles slowly pass from the mouth of the flask. Next take the spirit lamp and cautiously warm the flask. Be very

careful to keep the flame of the spirit lamp moving so as not to crack the glass. Notice that the bubbles now leave in a more rapid stream, but no water yet enters the glass.

Now remove the spirit lamp and let the air in the flask cool. The water will be seen to rise slowly in the neck of the flask. If the cooling be hastened by pouring cold water over the globe, the water will be observed to enter more rapidly.

*Explanation:* The hands being warmer than the air, they caused the temperature of the air in the flask to rise. This rise in temperature was accompanied by an expansion of the air which is shown by the bubbles leaving the flask. The expansion was further proved by the fact that the remaining air in the flask still completely filled it. This is shown by the inability of the water to enter, although some air escaped. On applying more heat, the expansion became greater, as is shown by the greater number of bubbles escaping from the flask, and by the fact that the water could not enter although a very considerable amount of air had escaped.

The cooling of the flask shows that cooling causes air to contract. Thus it is quite clear that air expands when heated and contracts when cooled.

**Effect of Temperature Variations on Atmospheric Pressure**

As we are quite well aware, the atmosphere is very unequally heated. We are also just as familiar with the fact that its temperature is constantly changing. Now the slightest variation in temperature produces, as we have seen in the last experiment, a considerable variation in the volume of the air and, therefore, in its density. These changing and unequal conditions of temperature and density lead to continual differences in atmospheric pressures, with the result that disturbances are set up in the atmosphere. These disturbances are familiar to us as winds and storms. On a smaller scale we know them in our houses as draughts, and use them in heating and ventilating.

**Experiment 26.**—*To find out what happens if a mass of air be unequally heated.*

*Apparatus:* A box with a glass front having two holes in the top, which are covered with glass lamp chimneys; a smoky torch, made from a piece of cotton batting bound to a stout wire with fine wire, and soaked in turpentine; a candle.

*Procedure:* Arrange the apparatus as shown in **Fig. 36**, but do not light the candle. Hold the smoking torch over each chimney in turn and note that its smoke shows no tendency to be disturbed when so held. Now light the candle and bring the torch over the chimneys once more. Observe that the smoke is strongly drawn down that chimney which is not over the candle; also that the smoke travels across the box toward the candle and passes out by way of the chimney above it.

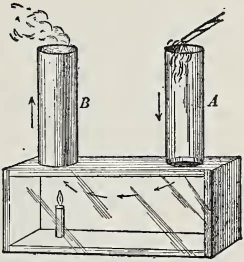


**Fig. 36.—Convection Current of Air**

*Explanation:* The arrangement causes the air to be warmer at one side of the apparatus than at the other.

The air so heated expands and is thus less dense than at any other part of the apparatus. It therefore rises, because it is forced upwards by the cooler, heavier air surrounding the candle. Thus a current of air is started which travels down the cool chimney and up the warm one. That the flow is due to the unequal heating in the box is shown by the fact that, while the candle was not lighted, no flow of air could be detected by the torch. It will be seen that one of the effects of unequal heating of the air is to form currents. Such currents are called *convection currents.* They are formed in either liquids or gases by altering the pressure at any point within the fluid. This alteration of the pressure may be brought about by:

1. Heating one part of the fluid more strongly than the rest.
2. Cooling a part of the fluid to a greater extent than the rest.
3. Mechanically building up a high or low pressure with pumps or fans.

**Uses of Convection Currents**

Convection currents are put to practical use in our homes in several ways. All ventilation systems are dependent upon them. Without their aid, the warming of buildings would be a very difficult and expensive, if not an impossible, undertaking. Coal oil lamps, candles and other similar illuminating devices could not operate without them. The preservation of perishable food-stuffs in refrigerators is partly dependent upon convection currents.

Supplies of hot water and steam heating systems are likewise dependent upon convection currents induced in water as well as in the atmosphere.

**The Use of Convection Currents in Heating a Room**

The heating of a room by a radiator or a stove is a familiar example of a convection current set up by making some of the air in the room hotter than the rest. The arrows in Fig. 37 show the general directions of the current. The pressure of such a current may be demonstrated by the aid of a smoky torch. It will be observed that the warm air in contact with the radiators or stove rises, while the cooler air in other parts of the room flows along the floor to take its place. As the heated air leaves the radiator or stove, it becomes cooler, showing a tendency to drop back again. It is prevented from doing so by the steadily ascending stream of warmed air pushing at it from below. On reaching the ceiling, this current of warm air is deflected, so that it now travels towards the cooler parts of the room. In its passage the warmer air gradually cools and sinks towards the floor, where it is caught by the horizontal cold current near the floor and pushed over the radiator or stove again. This circulation of air is always taking place in rooms heated by radiators and stoves. The convection currents carry the heat from the radiator or stove, and distribute it throughout the room. In this manner all our dwelling houses and public buildings are warmed.

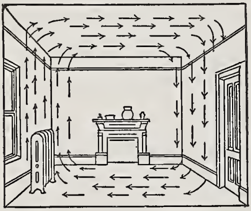

**Fig. 37.—Convection Current of Air in a Room**

*The chimney* is another example of the practical use of convection currents. Everyone knows that in order to make a stove burn properly it is necessary to obtain what is usually called a draught. Now such a draught is nothing more or less than a convection current deliberately created in a definite place and in a definite direction. It is the function of the chimney to create this current, by isolating a small fraction of the air in a building so that it can be warmed much more quickly than the rest, with a view to establishing rapidly an upward-moving current of warm and, therefore, light air. The hot, gaseous products and the smoke particles formed during burning are pushed up the chimney by the cold, heavier air which enters under the fire. When the fire is first lighted in the stove or furnace, the draught is poor, because the air column in the chimney has not yet become heated. The greater the difference between the weight of the air outside the chimney and that inside it, the stronger will be the draught produced.

**How a Chimney Works**

In building chimneys the following precautions are taken so as to ensure a good draught:

1. The chimney is built as straight and as smooth as possible.
2. It is made to extend above the other portions of the buildings.
3. It is kept away from an outside wall, so that it will not cool off too readily.
4. It is built exactly so that it will not be too large for the hot gases to fill, nor so small that it would obstruct their free passage.

*The refrigerator* is a food-preserving device which makes use of convection currents. The current is started by strongly cooling one part of the refrigerator,

namely, the ice chamber. This cooling causes the enclosed air to become denser at this point and so to fall. This cold, denser air in falling abstracts heat from the materials over which it passes. Becoming warmed in this manner, it attempts to ascend, but the downward push of the cold air leaving the ice box forces this warmed air down, until it is deflected by the bottom of the box. It now divides and rises up the sides of the box until it reaches the ice chest again. There the heat it collected is used to melt more ice. It is thus made heavier and, falling, starts on the circuit again.

**Convection Currents in Refrigerators**

*Hot air systems of heating*—These systems all operate by making use of convection currents. The currents are started by strongly heating a small fraction of the air of the building at some point below the ground level. The usual plan is to surround a stove with a shell or jacket of galvanized sheet iron. The air between the stove and its shell is heated and pushed up into pipes or flues by the colder, heavier air outside. These pipes lead the hot air to different rooms, which it enters through the hot air register. In this way convection currents are set up in every room, in the manner already explained. The cold air from the outside is led into the base of the jacket by the pipes connected with cold air registers. One cold air register is usually to be seen in the hall of a dwelling house near

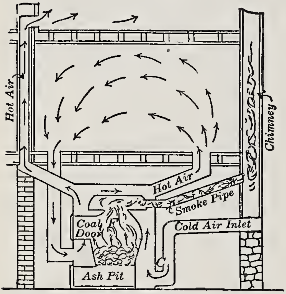

Fig. 38.—Hot Air System of Heating

the front door; a second near a window of the living room.

*Ventilation* is always obtained by convection currents. Sometimes these are set in motion by heating or cooling as explained above, or they may be induced mechanically by the use of fans or pumps. The study of ventilation systems will be taken up in a later chapter.

*Natural convection currents*—These are familiar to us as draughts, breezes and winds. They are always caused by variations in atmospheric pressure. These variations have two main causes:

1. The unequal heating of the earth's surface by the sun's rays.

2. The variations in amount of water vapour.

The former is more important in the formation of natural convection currents. The unequal heating of the earth's surface is due to:

(a) The varying slant of the sun's rays.

(b) The nature of the substance on which the rays fall.

(c) The presence of mist or cloud which screens the surface of the earth from the rays.

**Unequal Heating and its Several Causes**

We all know that the sun's rays strike the surface of the earth at different angles. These differences are the result of the motions of the earth and sun and the curvature of the earth's surface, together with the tilting of its axis. When the sun is low, as in the early morning and late evening, its rays have to penetrate a greater amount of air than at noon. Therefore it is colder at sunrise or sunset than at noon, unless some very definite local condition interferes.

It is warmer in summer than in winter because

the average height of the sun in the sky is greater in summer. The earth's shape affects the temperature of its surface very definitely. The earth is not a true sphere in shape, being slightly flattened at the poles. The tilt of the axis of the earth always holds one pole toward the sun and the other away. In addition, this tilting causes the polar regions to receive the sun's rays at a very low angle. These areas are therefore colder than the rest of the earth.

A water surface absorbs heat slowly, and retains this heat for a long time. Land surfaces take heat rapidly and lose it much more quickly than do water areas. Also bare, rocky or sandy places heat up and cool off far more quickly than do those covered with vegetation. Thus there are always great differences in the temperatures of the air over continents and oceans. In addition, the varying depths of water, or the changes in the character of the land surfaces, produce other inequalities in the air temperatures throughout these areas.

Mists and clouds produce unequal temperatures in two distinct ways:

1. By locally screening the water or land surfaces from the direct rays of the sun. Whenever a cloud passes between us and the sun we are at once aware that a smaller amount of heat is being received.

2. By preventing the heat which is reflected and radiated from the earth's surface from passing into space.

These two actions result in the cloudy days being cooler than sunny ones, because the earth is receiving fewer direct rays, while cloudy nights are warmer than clearer nights, because less heat can pass away.

The unequal temperatures found within the atmosphere result in the production of regions of high and

low barometer pressure. Low pressures are produced at points having the higher temperatures, and high pressures are found where the temperatures are lower. Differences in air pressure result in a movement of the air between them. The direction of the motion is always towards low barometer pressure and away from high barometer pressure.

Such motions in the atmosphere are called winds. The velocity of the wind is dependent upon the difference in air pressure. The greater the difference in the barometer reading between two points, the stronger the wind will blow between them.

**Land and Sea Breezes**

One of the simplest examples of the formation of a wind is afforded by land and sea breezes at the sea side, or on a smaller scale the on-shore and off-shore breezes noted, in summer time, at lake-side resorts. In the day time the land is heated to a higher temperature than the water. This causes a lower barometer pressure over the land than exists over the water, and the air flows from the water to the land producing a sea or lake breeze. At night the earth cools more quickly than the sea, and the barometric high and low are reversed. When this happens the direction of the wind is also reversed and a land breeze or off-shore wind produced.

**The Distribution of Atmospheric Pressure**

A careful study of the average barometric pressures at the surface of the earth reveals the existence of certain constant atmospheric conditions. These are, of course, strongly modified in places by the presence of local agents. Yet, notwithstanding these local variations, they present certain permanent features which are well known to us under the names of the Doldrums, the Trade Wind Belts, the Horse

Latitudes, and the Regions of the Westerly Winds. These features are all the result of the general circulation of the air around the earth, and similar features would be found on all planets possessing an atmosphere. So this general circulation is often called the Planetary Circulation, and the winds due to it, the Planetary Winds. This great circulation of air is really a huge system of convection currents, produced because the air over the Doldrums region is more strongly heated than at any other place on the earth.

**The Doldrums**

The Doldrums is the name given to the region of low-pressure calms found in a belt of 10° on either side of the equator. Within this belt the air is heated more strongly than at any other point, because within this region the earth receives the sun's rays more nearly vertically than anywhere else. In consequence, the earth is girdled within the region of the Doldrums by a belt of very light, strongly-heated air which is always being forced upward. The ascending air is usually heavily charged with water vapour. As it rises it expands and cools, the vapour condenses, and the region is therefore noted for its heavy rainfall. In the days of the sailing ship the prolonged periods of calm and the hot, rainy, depressing weather earned for the region its popular name, the Doldrums.

**The Trade Winds**

As the heated air above the Doldrums rises, the cooler air on either side of the ascending current rushes in to take its place. This horizontal movement of the air from the north and south toward the equator is what we know as the Trade Winds.

Owing to the motion of the earth these winds do not blow directly from the north or south, but are deflected, so that they blow from the north-east in the

northern belt, and from the south-east in the southern belt. The principal characteristic of the Trade Winds is their regularity both in direction and steadiness of pressure. It is to this fact that they owe their name, which, like the name Doldrums, is an echo of the old sailing-ship days. The region of the Trade Winds, in both hemispheres, is marked by clear blue skies and scanty rainfall. The world's greatest deserts are found in these regions, and they are the direct result of the Trade Winds.

**The Horse Latitudes**

As the heated air leaves the surface of the earth in the region of the equator, it is rapidly cooling and shows a tendency to fall. It cannot do so because of the steady rush of the Trade Winds underneath. It therefore flows northward and southward, finally reaching the surface of the earth at about 30° north and south latitude, where it produces those regions of high barometric pressure called the Horse Latitudes. They are regions of high-pressure calms due to the downward stream of cold heavy air. On striking the surface of the earth this stream divides, one part returning to the equator as the Trade Winds, and the other flowing toward the poles. This latter portion gives rise to the north-west and south-west winds of the north and south temperate zones respectively.

**The Westerly Winds**

In the last section we saw how these winds are formed by the dividing of the returning air currents from the Doldrums region. On this account they are sometimes spoken of as the Anti-Trades. They are found within two broad, well-marked belts between latitudes 35° and 55° in both hemispheres.

The Westerly Winds exert a profound influence on the climate of these belts, as they are great rain

carriers. Whenever they cross mountains they are rain-bringing winds on the windward slopes, and drying winds on the leeward slopes. The heavy precipitation of rain on the western slopes of the mountains in British Columbia and the scanty rainfall on their eastern slopes is a typical example of the effect of the Westerly Winds. The prevailing Westerly Winds are not nearly so constant, in either direction or steadiness of pressure, as are the Trade Winds. This makes for variety in weather, resulting in climatic conditions which are favourable to the production of a great variety of animal and plant life. This variety of climatic conditions and natural products is most marked in the northern belt. Here the land area is much more extensive than the water area, with the result that no other zone has such a complex distribution of temperature, sunshine and rainfall. In consequence it possesses a greater variety of plants, animals and men than any other of the world's great zones. The variations in climate and products of this zone also exert a great influence on the character of its inhabitants. Here are to be found the most progressive and highly civilized nations of the world. A study of Fig. 39 will assist you to memorize the facts with regard to the Planetary Circulation of


**Fig. 39.—Planetary Circulation of the Earth's Atmosphere**

the earth's atmosphere, and its main effects on the earth as the home of man.

Besides the great system of planetary winds, there are to be found upon the earth three other types of natural convection currents. We may conveniently classify them as seasonal winds, daily winds, and variable winds. The most striking example of a seasonal wind is the Monsoon.

*Monsoons* are seasonal winds which blow alternately from the land to the sea and from the sea to land.

**What are Monsoons?**

In summer the great land masses attain a much higher temperature than do the seas. Consequently, areas of low barometric pressure form in the air above the land, and strong air currents set in from the sea to the land. In winter, these land areas cool to a lower temperature than do the adjacent seas. This results in low barometric pressure appearing over the seas so that the air currents now flow from the land to the sea. The monsoon winds are rain-bringers when blowing from sea to land, and drying winds when blowing in the opposite direction. Consequently, lands affected by monsoons have only two seasons, a wet and a dry season. Sometimes, however, a country lies in the path of more than one monsoon. Such lands may have an almost continuously wet season. Ceylon and the southern tip of the Indian Peninsula afford an example of an area affected by more than one monsoon. Monsoons are developed only in the Tropics and, even then, only where a sea or ocean is nearly surrounded by warm lands. The most perfect condition for the production of monsoons is to be found in the lands surrounding the Indian Ocean. Other areas are the Gulf of Guinea and the Caribbean Sea. The monsoons are of great economic importance to the

lands over which they blow. In Southern Arabia the monsoon has caused the fertile strip along which coffee was first grown. Indeed, this is the only part of Arabia having a dependable rainfall. In Peninsular India the rain-bearing monsoon is anxiously awaited every year. If it comes too late or too early, crops are destroyed, or seeding is prevented; and then famine, often followed by an outbreak of epidemic diseases, stalks through the land. In some of these terrible famines three-quarters of the population of whole provinces have perished. Monsoon lands long held the monopoly of crops like coffee, tea and rice. Even yet these lands are the chief producers of these valuable crops.

**Daily Winds**

Examples of daily winds are the land and sea breezes already described. In addition we may consider mountain and valley breezes. In mountainous districts in calm weather, these breezes alternate as regularly as land and sea breezes. The mountain breeze is a cold wind which springs up in the late evening. It lasts all night, but stops in the morning. Somewhere between 9 and 11 a.m. a wind springs up which moves along the valley towards the mountain. This wind increases in force all the afternoon, but slackens at sunset. This valley wind is warm and damp and often wraps the peaks in mist. The cause of mountain and valley breezes is the same as that of land and sea breezes. During the day the air is less dense on the mountains than over the plains, and the convection current moves from the plains to the mountain tops. During the night the conditions reverse and the convection current moves from the peaks towards the plains.

*Variable winds*—In this class fall those atmospheric

disturbances called storms, cyclones, hurricanes and typhoons.

These are local and temporary disturbances which interfere with the regularity of the general system of prevailing winds. A storm is usually marked by an increase in the velocity of the wind and accompanied by rain or snow.

**What are Storms?**

*Thunderstorms*—These are storms which occur chiefly in warm regions and during the summer season in the temperate zones. They are characterized by rapidly rising air currents, a sudden squall of wind, lightning, hail, and a heavy downpour of rain. They may be terribly destructive in their effects.

*Cyclones*—The great majority of variable winds are, however, minor features of what are known as cyclones and anti-cyclones. A cyclone is a great spiral whirl of wind moving inward and upward around regions of low barometric pressure. In the northern hemisphere the spiral always has an anti-clockwise movement, but in the southern hemisphere they are always clockwise.

**Cyclones and Anti-cyclones**

*An anti-cyclone* is a great spiral whirl of wind moving outward from a region of high barometric pressure. The motion is clockwise in the northern hemisphere and anti-clockwise in the southern hemisphere. These great whirls travel through the atmosphere somewhat as eddies may be seen moving through water. In the air the cyclones and anti-cyclones travel in a general easterly direction around the earth. In their progress across the continents and oceans they bring about successive changes of weather. This passage of the cyclones across Canada is one of the factors controlling Canadian weather

conditions. It must be stated here that there are two distinct types of cyclones:

1. Those found in Temperate Regions.
2. Those found within the Tropics.

The cyclones of the temperate regions are usually very wide spirals often more than a thousand miles in width. They are seldom destructive and are the chief cause of the variability of the weather conditions in these regions.

*Tropical cyclones,* on the other hand, are sudden and violent storms. The pressure system causing them is similar to that of the temperate cyclones described above, the main differences being in the smaller areas covered and the greater difference in barometric pressures between the centres of high and low pressure. At the centre of the tropical cyclone is a calm area where there is little or no rain or cloud. This is called the "eye of the cyclone". As the tropical cyclone passes over a place the wind gradually increases in intensity and the rain falls in torrents. The velocity of the wind may reach one hundred miles an hour. The sea is lashed to fury and the waves roll "mountains high", while the barometer falls rapidly. Then comes a brief calm as the "eye of the cyclone" reaches the place. When this passes the wind again attains terrific velocity, but is moving in the opposite direction; rain falls again, and the barometer rises. Gradually the speed of the wind slackens and conditions become normal once more. These are the dreaded circular storms, so destructive to sailing ships, which gave the name cyclone and its accompanying idea of great violence. Tropical cyclones originate in calm regions and are believed to be due to the setting up of very rapid convection currents in an otherwise still atmosphere. Tropical cyclones are called hurricanes in the West

Indies and South Pacific, typhoons off the east coast of Asia, and cyclones in the Indian Seas.

**Tornadoes**

Tornadoes are terribly destructive winds which are often confused with cyclones. For some reason which is not very clear they are far more common over the great central plains of North America than in any other region of the world. The path of a tornado varies in width from a few rods to about half a mile. It is not often wider than this. Within this path the passage of a tornado is accompanied by fearful destruction; buildings are wrecked, trees uprooted, and many strange effects produced. Human beings find safety only by retreating into cellars. The velocity of the wind along this narrow path is so great that it has been known to drive straws several inches into boards, and to strip chickens of their feathers. The chief visible feature of a tornado is the funnel-shaped cloud which is always in contact with the ground when destruction is in progress. This funnel is sometimes balloon-shaped and sometimes coiled like a great, writhing snake. The passage of a tornado is always accompanied by a loud roaring sound. The forward movement of the tornado is on an average about 25 miles an hour. Its speed of rotation, however, is terrific. From the nature of the effects produced it has been calculated to amount to 500 miles an hour in some cases.

**Waterspouts**

Waterspouts are disturbances, similar to tornadoes, which occur over the ocean, but are not nearly so violent. They range in height from 300 to 3000 feet or more. A very large one was observed near Cape Comorin by the British steamer "War Hermit". From measurement made by the ship's officers it was found to

be 4600 feet high to the base of the overlying cloud. The water column was 500 feet wide where it joined the cloud and 1500 feet wide at the sea. Spray was thrown up to a height of more than 300 feet over an area 250 feet in diameter.

## QUESTIONS

1. How do variations of temperature affect the density of air?
2. Explain how air is circulated by a hot radiator placed at one side of a room.
3. What are convection currents? State three ways by which they may be originated. Give an illustration of how each method is made use of in the household.
4. Make a sketch of a refrigerator, showing by arrows the direction of the convection currents produced. Mark the coldest and warmest parts of the refrigerator.
5. How does a chimney create a draught?
6. Why is it cooler at sunrise or sunset than at noon?
7. How does the shape of the earth affect the temperature of the air at its surface?
8. Why are cloudy days cooler than sunny ones?
9. What are the Planetary Winds?
10. Where is the region known as the Doldrums found? How did it get its name?
11. What is the effect of the westerly winds on weather?
12. What are monsoons? Of what importance are they to (a) Egypt, (b) India?
13. In what important respects does the air within the region of the Horse Latitudes differ from the air over the Doldrums Region?
14. Why does the region of the Westerly Winds show a so much greater variety of plants, animals, and men than any other of the world's great climatic zones?
15. What is the difference (a) between a cyclone, and an anti-cyclone, (b) between a cyclone and a tornado?

## CHAPTER VIII

## THE COMPOSITION OF THE ATMOSPHERE

**What is it made of?**

The previous four chapters in this division have been mainly confined to a study of some physical properties of the air and their useful applications. We are now to study its chemical properties and some of their more important effects. One of the first questions we ask about any new substance is nearly always "What is it made of?" Finding out what things are made of is one of the most important duties of a chemist.

**Is Air a Simple Substance?**

In finding out what a thing is made of our first efforts should be to determine whether the substance is composed of one or more constituents. A substance having only one constituent is called a "simple substance". Let us try to discover if air be a simple substance.

**Experiment 27.**—*To find out if air is a simple substance.*

*Required:* A wide-mouthed glass bottle, a pie plate, a short piece of candle, some water.

*Procedure:* Light the candle and stick it to the pie plate with some of the molten wax. Nearly fill the pie plate with water. When the candle is burning well, cover it with the glass bottle and observe the result.

*Observation:* The candle continues burning for a few moments, but soon begins to die down and finally goes out. At the same time the water rises in the bottle. It will be noticed that no matter how long the apparatus be left, the water will not rise higher than approximately one-fifth of the height of the jar.

*Deduction:* This experiment clearly shows that only part of the air helps things to burn, and that there is another part which will not assist things to burn. We therefore conclude that the air cannot be a simple substance. In addition, we

conclude that this active part of the air forms about one-fifth of the whole amount and that the remaining four-fifths of the air is inactive.

The question now arises—what is this active part of the air, and what is the inactive portion? Careful investigation by chemists has resulted in the identification of the active part with the gas which they call Oxygen. The remaining four-fifths, the inactive part, consists of a mixture of several gases and solids, but is mainly Nitrogen.

**Air is a Mixture**

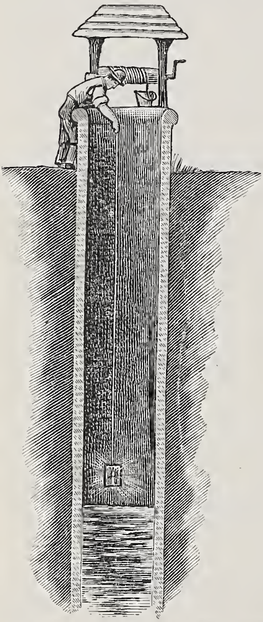

Fig. 40. — Workmen often lower a lighted candle into an old well before descending, in order to test if carbon dioxide is present in too large a proportion for safety.

Very careful analysis of many samples of air leads us to believe that it consists of Oxygen, 21 per cent., and Nitrogen, 78 per cent., together with very variable quantities of water vapour, carbon dioxide, dust particles, and five very strange and inactive gases called Argon, Neon, Krypton, Xenon and Helium.

The composition of the air is always varying. Sometimes it contains so much carbon dioxide as to be dangerous to breathe. The difference in the quantity and kinds of dust is very easily observed; the varying amounts of water vapour are easily observable in the differences between what we call damp and dry air.

## Experimental Demonstration of the Presence of the Principal Components of Air

**Experiment 28.**—*To show the presence of oxygen and nitrogen in the air and to measure approximately their volumes.*

*Required:* Tall glass jar, deep pie plate, iron filings, stick or glass rod, cheesecloth, water, two rubber bands.

*Procedure:* Make a small bag with the cheesecloth, and put some iron filings in it. Moisten the bag and contents, then tie it to the piece of stick or glass rod. Adjust the length of the stick or rod so that, when the glass jar is inverted, the filings will be held at the top of the jar. Fill the pie plate with water and invert the jar with the iron filings in. Place mouth downward in the water.

Bring the water level to the same height, slip a rubber band around the jar and adjust it to the water level. Set the apparatus aside for 48 hours, and at the end of that time note what has taken place. Next bring the water levels inside and outside the jar to the same height. This is done by pushing the jar further down into the water. With another rubber ring mark the new level of the water. The space between the levels marked by the two rings was that occupied by the oxygen.

*Deduction:* 1. A part of the air has combined with iron to form a new compound which is red in colour.

2. The water rose in the jar to about one-fifth of the whole volume.

3. The remaining four-fifths of the air which would not combine with the iron is principally nitrogen.

4. This experiment, therefore, shows the presence of two of the components of the atmosphere, namely, oxygen and nitrogen. Oxygen is that part used up when things burn, or metals rust in the air. Nitrogen is the inactive part which is not used up.

**Experiment 29.**—*To show the presence of carbon dioxide in the atmosphere.*

*Required:* Fresh lime water, three saucers or other shallow dishes.

*Plan:* Carbon dioxide is the only colourless gas which will turn lime water milky. Therefore, if we expose lime water to the atmosphere it will turn milky, if carbon dioxide be a component of air.

*Procedure:* Place a saucer on the floor, another on a table, and the last on a shelf on the top of a cupboard, taking care they are not in draughty places. Pour lime water in each and leave for several minutes.

*Observation:* On examining, we shall find them all covered with a milky film or scum. The one on the floor will have the heaviest coating, and the one on the cupboard the lightest.

*Deduction:* Carbon dioxide is present in the atmosphere, and it is a heavy gas having a tendency to settle in low places.

**Experiment 30.**—*To demonstrate the presence of water vapour in the atmosphere.*

*Required:* A highly polished metal cup, water, and chipped ice.

*Procedure:* Place some water in the cup and add ice, stirring all the time. As the temperature drops the bright metal surface becomes dimmed. On examination, this is seen to be due to a film of moisture deposited on the outside. The chilling must have caused the water vapour present in the air to be condensed on the cup, since the outside of the cup has been in contact only with the atmosphere.

**Experiment 31.**—*To show the presence of dust in the atmosphere.*

The presence of dust in the atmosphere may be shown by admitting a beam of light into a darkened room. The path of such a beam is made visible by the illumination of countless tiny particles which may be seen dancing in the path of the beam. The beam may be introduced by allowing the sunshine to enter through a small hole cut in a blind or shutter. If this is not convenient, the beam from an electric pocket flash lamp or an optical lantern may be used. There are many common, everyday observations which impress upon us the fact that there are large quantities of fine dust particles floating in the air. For example, the furniture in a room requires frequent dusting. The white snow soon becomes darkened by the steady accumulation of dust particles on its surface.

## The Natural Importance of the Principal Components of the Atmosphere

We have already learned that the atmosphere is a mixture of several gases and dust particles. Four of these gases, viz., Oxygen, Nitrogen, Carbon dioxide, and Water Vapour, together with the dust, are of far greater importance than the rest. All of these five substances play such valuable parts in the processes of nature, that, if any one of them were to be removed or if their balance should be seriously disturbed, very disastrous consequences would follow.

Oxygen is the most useful of all elements. Atmospheric oxygen is essential to all animal and plant life.

**The Natural Importance of Oxygen**

It is necessary for the production of light, heat and power from fuel. The oxygen of the air is the great factor in the production and maintenance of bodily heat. Without it the disposal of sewage and other waste materials would become a nuisance and a menace to health.

By combustion most people understand the burning of substances, accompanied by heat, light and

**Oxygen and Combustion**

flame. This idea, however, is not quite correct, for although heat is always produced during combustion, light and flame may not be. The truth is that ordinary burning is simply one form of the process of chemically uniting substances with oxygen. The chemical union may take place in any one of the three following ways:

1. *Slowly* as in the rusting of iron, decay of wood, or rotting of manure. In slow combustion heat is always produced, but light and flame are not.

2. *Rapidly* as in the burning of wood or coal in a stove, of gas in a fireplace or stove, of oil in a lamp, or of wax in a candle.

3. *Instantaneously* as in the explosion of dynamite in a mine, powder in a gun, or of gasoline vapour and air in the cylinder of an internal combustion engine.

From the time when man first learned to make a fire, combustion has been one of his greatest helpers. For many centuries it was the only source of heat for the cooking of food and the fashioning of tools and weapons. Until the last quarter of the nineteenth century it was the only means by which artificial light could be obtained.

The real nature of combustion has been the subject of much speculation ever since man first began to think about the things around him. Many very queer notions were held about burning by the great thinkers of the past. The true explanation of burning, namely, that it was the union of a substance with the oxygen of the air, was finally given by the French chemist Lavoisier. The work of Lavoisier was made possible by the patient and careful work of several other investigators, the chief of whom were Cavendish and Priestley in England, and Scheele in Sweden. Lavoisier's explanation of the true nature of burning is very important because it changed many preconceived ideas and started a new age in science. For this reason Lavoisier is often called the "Father of Modern Chemistry."

*Slow Combustion* is said to occur when the union of a substance with atmospheric oxygen occurs without the production of light and flame. Examples of this form of combustion are very common. We shall consider three definite cases, viz., the rusting of iron, the decay of animal matter, and the decay of plant matter.

**Rusting of Iron**

That iron, if left exposed to the air, soon becomes rusty is a fact well known to almost everyone. If the iron be left exposed long enough it will be completely changed into a reddish-brown powder which is familiarly called iron rust, but the correct name of which is oxide of iron. This conversion of iron into an oxide may be made to take place quickly with the production of heat and light, by burning some iron wire in a jar of oxygen gas. Now the slow change of iron into rust on exposure to the air is essentially the same thing as burning iron in oxygen. The difference is only in the speed

at which the combustion is accomplished. In the case of burning iron in oxygen the change occurs rapidly, so that the rise in temperature is sudden and noticeable. On the other hand, rusting may occupy weeks or months, and therefore the rise in temperature is too gradual to be noticed.

It has been shown by careful experiments that iron will not rust except in the presence of moisture. In most countries there is usually sufficient moisture present in the air to make the rusting of iron and steel inevitable. When we consider the enormous use of iron and steel for our bridges, railroads, ships, engines, machinery, pipe lines, tools, containers, etc., it will be seen that the prevention of this inevitable rusting of iron and steel becomes a problem of great importance. There are many ways of covering iron to prevent rusting. The most common are painting, galvanizing, and tinning.

*Painting* has several advantages over the other two methods:

1. It can be easily applied when the iron is in position.

2. It is readily renewed without dismantling the structure.

3. Paint can be had in many colours, and so the structure may be made to harmonize with its surroundings.

*Galvanizing* is a process by which the iron is given a coating of molten zinc. This provides a good protection when properly and skilfully carried out, but it has the disadvantages of being almost impossible to renew, and that the galvanizing must be done before the iron is put into place. Galvanized iron is most commonly used for roofing, for fencing, for telephone

wires, and for tanks, baths, pails, and other similar small hollow ware.

*Tinning*, like galvanizing, is a process by which sheets of iron are coated, but in this case with tin instead of zinc. One of the most important uses of tinned iron is for the making of so-called "tin" containers for canned food.

**The Decay of Plant Matter**

Everyone is familiar with the fact that, when a plant dies, the process which we call decay sets in. Not many people, however, realize that this decay is essentially the same process as the burning of a wood fire. Yet there is no doubt that it is so. There are only three points of difference:

1. The rate at which the change takes place.

2. The means by which the combustion is brought about.

3. The lack of flame and light.

The final result is, however, exactly the same; that is, the plant material is caused to unite with the oxygen of the atmosphere, producing several different simpler substances. These new and simpler compounds are mainly carbon dioxide gas and water vapour. The decay of the trunk of a tree may take as many years as its burning would take hours; yet the amount of heat generated in the two cases would be exactly the same. The detection of this heat in the case of the decaying tree trunk, however, can only be made by the most careful observation. But there are many cases of plant decay in which the evolution of heat is rapid enough to be quite noticeable. As examples we may cite the heat of the gardener's hot-bed, the sweating of hay in stacks, of grain in heaps, storage bins, and warehouses. In these cases the slow

combustion is brought about through the agency of minute organisms, called bacteria, which thrive best when the hay or grain or manure heap is damp. As this heat cannot readily escape it steadily accumulates in the interior of the stack, until at last the temperature may rise high enough to cause the mass to ignite. When this occurs rapid combustion or ordinary burning sets in. Such conflagrations are generally referred to as examples of *Spontaneous Combustion.* This name was applied to such outbreaks of fire before the real nature of burning was understood. It should be remembered that there is nothing spontaneous about such fires, as combustion has been going on for a long time before its effects become visible.

Soon after the death of an animal its body begins to show signs that changes are taking place within it.

**Decay of Animal Matter**

Slowly but surely the complicated compounds forming its tissues are taken to pieces and converted into simpler ones. The principal agent concerned in this process of decay is the oxygen of the atmosphere. It is assisted in this work by water and bacteria. The water is present in the tissues of the animal and also as water vapour in the air. Bacteria, as we shall see later, are always present in the air. Decay is therefore a form of slow combustion or oxidation during which the soft kinds of animal matter are changed into gases, the principal ones being carbon dioxide, ammonia and water vapour. They enter the atmosphere and, mingling with it, are wafted away.

The hard kinds of animal matter like bones and teeth are converted much more slowly, but in the end they are changed by union with oxygen into powdery solids. These solids are dissolved in the soil waters and, ming-

ling with the surface waters of the earth, are gradually removed by them.

## Practical Applications of Oxidation

In all centres of human occupation the waste products, like garbage and sewage, are a constant danger to the public health. The safe disposal of such wastes is an expensive and difficult undertaking. Without the assistance of the process of oxidation it would appear to be an impossible task. Every plan for the disposal of waste depends upon some form of combustion. The garbage or solid matter capable of being burned is rapidly converted into carbon dioxide and water by burning in incinerators. Those solid materials which will not burn are buried, and, by slow oxidation, are gradually converted into harmless compounds. The liquid refuse, generally called sewage, is converted into harmless and inoffensive products by a slow oxidation which is accelerated by bacteria always present in such material. Cesspools and septic tanks are merely devices for bringing the sewage in contact for a longer time with the bacteria causing decay. The amount of sewage from cities is too large to be safely disposed of in cesspools and septic tanks. In such cases the sewage is often turned directly into a river, or lake, or the seas, where the sewage is oxidized by the oxygen dissolved in the water and converted into harmless compounds. Often the quantity of sewage is so great that it cannot be turned into a body of water without rendering the water unsafe. In such cases another plan is followed: the liquid sewage is first passed through beds of broken stone, sand or gravel. During its passage through these beds the sewage is attacked by bacteria and oxidation sets in, converting

**Waste Disposal**

the dangerous material into harmless matter and water. These products are then allowed to drain through pipes into the body of water.

*The Drying of Paints and Varnishes*—This is due to the slow oxidation of linseed oil into a tough elastic solid, and not to any loss of water.

Many manufacturing processes depend upon slow oxidation of plant and animal materials for a supply of heat and carbon dioxide; e. g., the very best white lead for paints is that produced by the "Dutch Process". This method consists of putting pieces of lead and vinegar into pots. The pots are then covered loosely and buried in tan bark. The tan bark is moistened and slow oxidation sets in, producing carbon dioxide and water accompanied by considerable heat. The heat causes the vinegar to give off vapours which attack the lead. The carbon dioxide then unites with the compound so produced, and makes the beautiful white pigment which is sold as white lead.

*Rapid combustion or burning* is the union of substances with oxygen accompanied by the production of heat and light and sometimes flame, e.g., the burning of a candle.

Let us now light a candle and try to find out what is happening while it is burning. When first lit, a candle burns brightly for a few moments. The flame then dies down, but soon springs up again and continues burning steadily. Can you explain why the candle flame behaves in this peculiar way? Now look at the candle as it is burning steadily. Observe the small basin-shaped hollow at the top of the candle. This is filled with melted wax. This molten wax is absorbed by the wick, and will travel like ink up a strip of blotting paper held in an inkwell. As the liquid wax

gets closer to the flame it gets hotter and hotter and finally begins to burn.

The point at which the wax becomes hot enough to burn is marked by the base of the flame. At this point the liquid becomes so hot that it turns into a gas. If the flame be closely examined, it will be seen that the burning occurs chiefly in the outer part of the flame and not right against the wick. It is possible to show the presence of this gas in a candle flame. Look at the candle flame and notice that there is a dark zone just around the wick. What is this zone? Is it the gas?

**Experiment 32.**—*To find out if the dark zone of a candle flame is composed of unburnt gas.*

*Required:* A burning candle, a piece of narrow glass tubing about 6 to 8 inches long, a retort stand and clamp, and matches.

*Procedure:* Support the glass tube nearly upright in the clamp with the lower end well within the dark part of the flame. After the tube has been in place for some time bring a lighted match over the tip and observe what happens. To ensure success, the candle flame must be shielded from draughts, and it may be necessary to keep the tube warm by running a spirit lamp or Bunsen burner flame up and down the tube, in order to prevent condensation.

After completing this part of the experiment remove the tube from the flame and let it cool. What do you see adhering to the inside of the tube?

*Observation:* The fact that combustion takes place at the tip of the tube shows that the dark zone contained unburnt gases. The material which condensed on the inside of the tube is quite easily recognized as wax.

*Conclusion:* We therefore conclude that the heat of the flame melts the wax, which then rises up the wick. When the liquid reaches the flame, it is converted into a gas which collects at the top of the wick, forming the inner dark zone of the candle. No burning is taking place in this dark space.

That this is so may easily be confirmed by performing the following simple tests:

1. Hold a match across the flame just above the wick for a moment. Remove it and see where the burning has occurred. Does this confirm your conclusion?

2. Hold a match head in the central part of a flame for a moment without lighting it. This can be done, but requires a steady hand and strict concentration on the job. Try it.

*The Parts of the Flame*—It has been shown in the last experiment that the flame of a candle is not a

simple one. As a matter of fact the candle flame consists of three distinct zones, each of which may be clearly observed:

1. There is the inner dark zone where no combustion is taking place.

2. A middle luminous zone where combustion is going on but is not complete.

3. An outer non-luminous zone of complete combustion.

The first two parts are quite easily seen and no one can mistake them. The third is not so easily observed since the brightness of the luminous zone obscures it. Its lower part, however, may be easily seen as a blue fringe about the lowest part of the flame. The whole zone may be made visible by tearing a piece of paper roughly to the shape of the flame and holding it before the eye in such a manner as to obscure the very bright part of the flame. The outer zone is then visible as a very pale greenish-blue mantle. *What makes the middle zone so bright and why is it called the zone of incomplete combustion?*

Experiment 32a.—*To show the presence of solid unburnt particles in a candle flame.*

*Required:* Candle flame, a common saucer, or other cold, white object.

*Procedure:* Hold the saucer in the flame of the candle for a few moments.

*Observation:* On removing the saucer from the flame, it is seen to be covered with a black deposit.

*Explanation:* This black deposit consists of tiny particles of carbon. They were floating about in the middle region of the flame, but because of the heat there they were white hot. It is the presence of these white-hot particles of carbon that gives a candle flame its power of emitting light. These particles get hotter and hotter as they approach the outer edge of the luminous zone. Here they find sufficient oxygen to enable them to be completely burned up, thus forming the outer zone of complete combustion. This zone does not give any light because the solid particles have disappeared, being completely converted into gas.

To sum up our results, we see that a candle is an ingenious combustion device in which the fuels are kept in a solid state until just a few moments before they are actually required by the flame. In this respect candles are superior to a lamp which uses liquid fuel, because there is nothing to spill, break or get out of repair. As long as the candle is burning it makes its own bowl or cup, which it automatically keeps filled with liquid fuel. This liquid fuel is next converted into a gas which combines with the oxygen of the atmosphere, producing a flame having three distinct areas. In burning, the wax or fat of the candle, which is composed entirely of carbon, hydrogen and oxygen, is entirely converted into carbon dioxide and water.

The light-giving property of the candle flame is due to unburned particles of carbon, floating about the middle region, being raised to white heat by the combustion which is taking place.

## QUESTIONS

1. Name four important components of the air. Explain how each contributes to the welfare of man.
2. Describe an experiment by which you may prove that air is not a simple substance.
3. Describe experiments, one each, to show that air contains oxygen, nitrogen, carbon dioxide, water vapour, and dust.
4. How is the supply of carbon dioxide and of oxygen maintained in the air?
5. What is combustion?
6. Describe the difference between slow and rapid combustion.
7. Give an illustration of instantaneous combustion.
8. Why is Lavoisier called "the father of modern chemistry"?
9. Explain the uses of both rapid and slow combustion in the disposal of sewage.
10. What are "tin-plate" and "galvanized iron", and why are they so useful?
11. How do paints and varnishes dry?
12. Describe, using a diagram, the structure of a candle flame, marking definitely the various zones. Then write a description of what is taking place in each zone, and account for the light emitted by one of the zones.

## CHAPTER IX

# OXYGEN IN RELATION TO PLANTS AND ANIMALS

The first stage in the life of any plant is germination. By germination we understand the awakening into action of the vital processes which are lying dormant in the seed. In order that seeds may germinate, three conditions are essential, (1) warmth, (2) moisture, (3) air.

**Germination of Seeds**

During the period of germination the tiny young plant lives for a time on food stored in the seed. Gradually the young plant secures a foothold in the soil, and when its leaves appear above ground it gathers food for itself. The plantlet is now able to shift for itself, and germination is complete. From the work already done we know that air is not a simple substance, but is a mixture of several substances. The question therefore arises, does the plant use all of these components during germination, or only one of them? A few simple experiments with seeds will enable us to answer this question with certainty.

**Experiment 33.**—*To find out if air is necessary for germination of seeds.*

*Required:* Some peas or beans, two tall glass jars, some sheets of glazed paper, sand, or moss, and boiled water which has been allowed to cool to air temperature.

*Procedure:* Trim the sheets of paper to the height of the jar. Fit each jar with a cylinder of the paper in such a manner that the paper touches all the inner surface of the sides. Fill the space inside the paper with sand or moss. Insert several seeds between the paper and the glass. Now carefully

fill one jar with the boiled water so that the seeds and sand or moss are entirely submerged. Mark this No. 1 and set it aside for about 10 days. Examine from time to time, and, if necessary, replace the water lost by evaporation so that the water level is never below the surface of the sand or moss. The object of boiling the water in this jar is to make sure that there is no air present in the water.

Take the second jar and mark it No. 2. Using fresh tap water, moisten the sand or moss and set it beside the first jar. Examine each day and keep moist by new additions of fresh tap water.

*Observation:* In about nine or ten days the seeds will have germinated in the second jar, but those in the first will not show signs of growth. On the other hand they may show visible signs of decay.

*Conclusion:* From this experiment we conclude that, if air is prevented from reaching the seed, it will not germinate, even though heat and moisture be present. Air is therefore necessary for germination.

**Experiment 34.**—*To determine which component of the air is used by germinating seeds.*

*Required:* A handful of peas or barley seed, two fruit jars and a tin can.

*Procedure:* Fill the tin can with the seeds and moisten with water. In a few days they will have swollen considerably. When this has occurred transfer them to one of the sealers and screw on the cover. Allow the other one to remain empty, but screw down the cover just the same.

1. In a day or two remove some of the air from the sealers by means of an eye-dropper or fountain-pen filler, and bubble it through fresh lime water.

2. Insert a lighted splint in each sealer and note the results.

*Observation:* The air removed from the sealer containing the sprouting seeds turns the lime water milky. That obtained from the sealer without seeds has no effect on the lime water.

The lighted taper is extinguished in the sealer containing the seeds, but continues to burn in the other one.

*Conclusion:* Recalling the experiments carried out in Chapter VIII, we are able to conclude from this experiment that seeds use the oxygen of the air in germinating, and produce carbon dioxide. It is also evident that slow oxidation is one of the processes which takes place when seeds germinate.

When its roots have formed, the young plant continues to take some of its oxygen from the air present in the soil. It is therefore necessary to ensure that a sufficient supply of fresh air may enter the soil. This

is called aeration of the soil and is accomplished by such operations as, hoeing, raking, digging, ploughing, and harrowing. The importance of these operations lies in the fact that they put the soil in the best possible condition for exchanging the used air in the soil for fresh air from the atmosphere. If the used air cannot escape from, and fresh air does not enter the soil, the growth of the roots is retarded. On such soils the plant growth is stunted and the farmer speaks of them as "sour soils". Free cultivation of such soils sweetens them by exchanging good air for foul, and so stimulates the root development with its resultant vigorous plant growth.

**Plant Respiration**

Of all the wrong ideas popularly held about plants, there is none which is held so firmly or widely as the belief that plant breathing is the opposite of animal breathing. This error is due to the confusion of breathing or respiration with something entirely different called *photosynthesis,* which we are to study in a later chapter.

The truth is that plants require oxygen for respiration just as animals do. The great difference between plant and animal respiration lies in the manner by which they obtain their oxygen from the air. Animals have special organs such as lungs and gills, through which they absorb oxygen. Plants have no similar adaptations. How then do plants absorb their oxygen? An experiment designed by Mr. C. Stuart Gayer of the Brooklyn Botanical Gardens will give us the answer to our question.

**Experiment 35.**—*To find out what part of the plant absorbs the oxygen used in respiration.*

*Required:* Seven rather tall jars (olive bottles are just the thing), some wire gauze, well fitting corks, sprouting seeds,

living plant stems, living roots washed free of soil, green leaves, opening flower buds, and fresh mushrooms or toadstools.

*Procedure:* Into each of the seven bottles fit a partition of wire gauze, so as to divide the space vertically into equal parts. Leave one bottle empty. In each of the other six jars fill the space on one side of the gauze only with the germinating seeds, living stems, living roots, green leaves, flower buds, and the mushrooms or toadstools (one only in each jar). Seal all the jars with good corks and set them in any convenient place not in direct sunlight. At the end of about 24 hours, test the air in each by means of a lighted taper or wooden splint. Take care in testing that the stoppers are not removed any longer than necessary to insert and withdraw the taper rapidly.

*Observation:* The air in the first jar will support combustion; that in the others will not. This shows that oxygen must have been removed from each of the six jars containing various kinds of plant material.

*Conclusion:* We therefore conclude that oxygen is used by the living plant, and also that all parts of a plant, viz., germinating seeds, roots, stems, leaves, flower buds, as well as those plants which we call fungi, absorb the oxygen and utilize it for respiration.

*Lenticels*—Many living cells and tissues of plants are so deeply buried in the plant body that they require assistance in obtaining their oxygen. Such deep-seated parts are most common in the stems and branches. If you examine a young woody twig, small dots or lines can be seen on the surface of the bark. These are called *lenticels.* They are very prominent in the cherry trees. These lenticels are small holes through which air can penetrate to the deeper tissues.

*Stomata*—On the underside of all leaves are tiny openings called stomata. Some of the deeper leaf tissues receive their oxygen through the stomata.

From the foregoing experiments and discussion it will be clear that fresh air is just as important for plants as for human beings. Many common everyday experiences confirm this idea. For example, plants kept in dusty or smoky places do not thrive because their breathing pores become choked with dust. They

suffocate just as truly as do animals under similar conditions. Again if a healthy plant is given so much water that the soil around it becomes water-logged, it will die because the air cannot reach its roots. Many trees, such as the cypress, grow in swamps. In order to obtain oxygen for their roots they grow very curious "knees", which project above the water, and so obtain the oxygen required for root respiration.

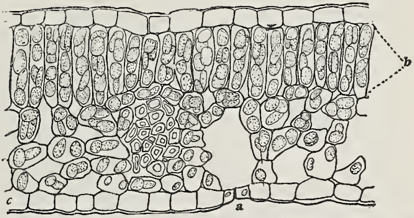

**Fig. 41.—Section of a Leaf, Showing the Air Spaces**
Breathing-pore or stoma at *a*. The palisade cells which chiefly contain the chlorophyll are at *b*. Epidermal cells at *c*.

Animals may live for quite long periods of time without receiving either food or drink, but if their supply of oxygen be cut off death occurs within a few minutes. Evidently, then, a constant supply of oxygen is a vital necessity to animals.

**Oxygen in Relation to Animals**

All the vital processes of living things are carried out by the energy supplied through a series of oxidations carried on in every cell of their bodies. These oxidations are accomplished by the process of respiration. In the simpler plants and animals the oxygen required is obtained directly from the air or water, and after oxidation has taken place the carbon dioxide produced is returned to the surrounding medium. In the higher and more complex animals and plants this direct respiration by each cell is impossible, since so many of their cells are not within reach of the surrounding medium. We have already seen that plants

overcome this difficulty by certain adaptations, for example, the stomata of the leaves and the lenticels of the bark. These simple devices suffice for the plants because their cells use comparatively little oxygen. Animals, however, require a much larger quantity of oxygen than do plants, because they are far more active. For one thing, an animal is capable of locomotion; a plant is not. The extra energy needed is produced within the animal body through a greatly increased rate of oxidation. Clearly, the higher animals must be equipped with some special adaptations for securing the extra oxygen. The process of securing extra oxygen is called *breathing* and is quite different from *respiration*. *Breathing* is a mechanical process by which pure air is exchanged for carbon dioxide and other gases produced during respiration. It occurs only within the special organ devoted to this action. *Respiration*, on the other hand, is the process of uniting oxygen with the contents of the cells, and the consequent production of carbon dioxide, water, and other wastes, together with the liberation of energy. The energy usually appears in the form of heat and motion. By respiration the cells are nourished, material is abstracted from the food for growth and repair of tissues, and energy to carry out the work of the organs of the body is produced.

Remember that respiration is always going on in all parts of the body, and that the cells of our fingers and toes, of the marrow of our bones and of the pulp cavities of our teeth, respire just as truly as do the cells of our lungs. Plants differ from animals in their respiratory processes by the absence of organs which mechanically exchange the used air for a supply of unused air.

Since animals are found in many surroundings we

should expect to find the act of breathing carried out in many different ways. Every animal is wonderfully adapted so as to suit the conditions under which it must live. The problem of securing the proper amount of oxygen for respiration under varying conditions has resulted in the development of many kinds of breathing organs in animals. These changes in the form of the breathing organs with differences of environment are called *adaptations.* We may classify animals according to their breathing adaptations into the following classes:

**Adaptations for Breathing in Animals**

1. Tube breathers, e.g., insects.
2. Skin breathers, e.g., earthworms.
3. Gill breathers, e.g., fishes, clams and oysters.
4. Double breathers, e.g., lung fishes.
5. Lung breathers, e.g., frogs, toads, newts, birds, snakes and mammals.

**The Respiration of Insects**

The respiration of insects is accomplished in a very different manner from that used by any other class of animal life. Their breathing organs consist of tubes, called *trachea,* through which fresh air is brought to the tissues and the carbon dioxide is carried away. The fresh air is admitted to the trachea through small openings on certain segments of the insect's thorax and abdomen. These openings are called *spiracles* or *stigmata,* and are easily observed on grasshoppers. The spiracles are connected by short branches to two main tubes, one on each side of the body. From these main tubes, branches penetrate to all parts of the body. These branch tubes divide and subdivide into very fine tubes forming a capillary network. The movement of air through this network of tubes is maintained by the rhythmic expansion and contraction of

the insect. This action of the abdomen may be easily observed in grasshoppers or wasps. When the abdomen is shortened, the impure air, charged with carbon dioxide, is forced out. Fresh air is drawn in when the abdomen is extended. The rate of expansion and contraction of the abdomen is very regular depending upon the temperature and activity of the insect. The respiration of insects also differs from the respiration of all other animals possessing blood, in that insects make no use of the blood as an oxygen carrier. Many insects have large air sacs connected with the main air tubes; these act as air reservoirs. Thus far we have been considering only the land forms of insects. There are, however, many insects which live in the water. These water-dwelling insects all possess the tube system of breathing, but they have developed several additional adaptations which assist them in securing fresh air in their water environment.

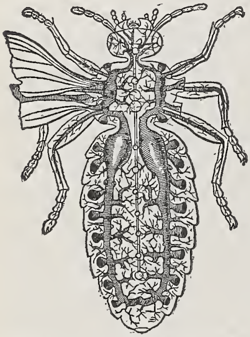

Fig. 42.—Air Tubes of Insect

Some of them, like the dragon-fly and mosquito nymphs, have *tracheal gills.* These consist of a leaf-like expansion, or tuft of fine threads, into which the trachea extend and divide to form a fine network. The oxygen of the air dissolved in the water passes through the gill membrane, mixing with the tracheal air and purifying it. True gills, that is, gills carrying blood vessels, like those of the fishes, are never found in insects. Other water-dwelling insects carry a tiny film of air with them. In some cases

this thin film of air is held by a thick coat of fine hairs on the insect's body; in others the air is held beneath the wing covers. Sometimes the trachea project from the abdomen as tubes which extend above the surface of the water, and so reach into the air, as in the mosquito larvae. The tube method of respiration is the most perfect method of supplying oxygen to the tissues of animals. There is little doubt that the wonderful activity, working power, and endurance of insects are mainly due to their splendid respiratory system.

Earthworms are not provided with special organs of respiration, but breathe directly through their skins.

**The Respiration of Earthworms**

An earthworm's skin is thin and the flesh just underneath it is well supplied with small blood vessels. As long as the skin is moist, oxygen passes through it into the blood, and carbon dioxide passes out of the blood into the surrounding air. If the skin becomes dry these exchanges cannot continue, and the worm suffocates. This does not mean that earthworms can live in water. They cannot, because the quantity of air dissolved in water is so small that the animal is unable to make exchanges of oxygen and carbon dioxide quickly enough. This is why so many earthworms are to be seen on the surface of the ground after a heavy rainfall. They have come out of their water-logged burrows to avoid suffocation.

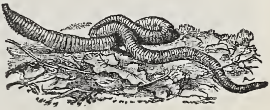

**Fig. 43.—An Earthworm**

Oysters live at the bottom of the sea, and cannot rise to the surface of the water to breathe. They

**The Respiration of Oysters**

must obtain all the oxygen required for respiration from the small amount of air dissolved in

the water. Oysters possess organs of respiration beautifully adapted to the conditions under which they must work. These organs are the gills and the mantle. The *mantle* is a thin, yellowish membrane completely covering the body and attached to the shell along its edges. Underneath the mantle and between it and the body hang the *gills,* two on each side. They are curved bodies, formed by a double series of very delicate canals, placed close together and perforated with many

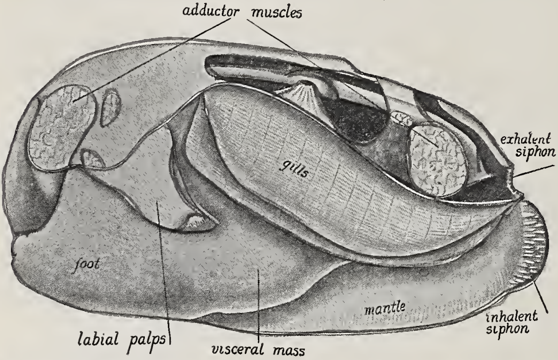


**Fig. 44.—Fresh Water Clam with Shell and Mantle Removed from One Side**

tiny holes through which water may pass. Both the mantle and the gills are well supplied with blood capillaries, through which the colourless blood is pumped by a three-chambered heart. This device brings quite large quantities of blood into very close contact with the dissolved oxygen in the water. The animal must cause a similarly large volume of water to pass over these blood capillaries so that the required exchange of gases may take place. The edges of the mantle folds are joined together ex-

cept at two places where openings called *siphons* are left. This produces a sort of bag with an inlet and outlet, which is called the *gill chamber.* The lower opening is surrounded by fine hairs called *cilia.* The surfaces of the gills are also covered with cilia. These are constantly moving together in one direction and then slowly returning to their original position. This waving or lashing of the cilia propels fresh water with

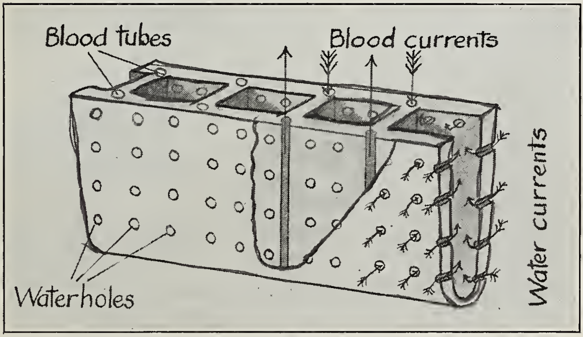


**Fig. 45.—Respiration of the Oyster.**

its dissolved oxygen through the lower opening or *inhalent* siphon into the gill chamber. It then passes between the gills, exchanging some of its oxygen for carbon dioxide, and goes to an upper passage. Finally it leaves the gill chamber by the other opening which is called the *exhalent* siphon.

All the water molluscs, such as clams, mussels, pond snails, scollops, cockles, squids, and octopi, breathe in this way. Indeed, perhaps the best example to study in the Prairie Provinces would be the fresh water clam, which can easily be obtained in any prairie stream with a gravelly bottom.

There are some molluscs which live on land, for example, slugs and land snails. These breathe by lungs and not in the manner just described.

**The Respiration of Fishes**

The respiratory apparatus of fishes is an adaptation for breathing the gases dissolved in the water. It consists of mouth, pharynx, and gills. Fishes usually have four pairs of gills situated at the sides of the head and covered with a stiff, but moveable flap, called the gill cover, or *operculum*. In some species, for example sharks, the coverings are absent, so their gills show as slits in the throat.

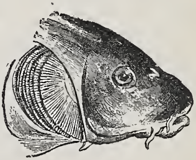

Fig. 46. — Carp, with Right Gill Cover Removed to Show the Gills

Each gill consists of three distinct parts. First there is an arch of bone so attached to the skeleton of the head that it can swing outwards, somewhat like a door on its hinges. This is called the *gill arch*. Around the outer side of this arch are the soft, deep pink *gill filaments*. These filaments are very plentifully supplied with blood capillaries and have a very thin and delicate skin. It is here that the exchange of gases between the water and the blood takes place. On the inside of the gill arch may be seen a row of spiny projections called *gill rakers*. These organs have nothing to do with breathing. They serve as a sieve to prevent the food from passing out of the mouth, and also to protect the delicate gill filaments from injury by hard and spiny food materials. Respiration is effected by drawing water through the mouth into the pharynx and ejecting it through the gill slits.

During *inspiration* the mouth opens, the gill covers move outwards and in so doing close the gill openings

by drawing a membrane over them. The water rushes into the enlarged mouth cavity. During *expiration*

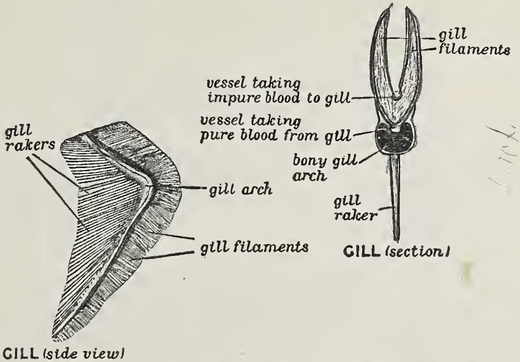


Fig. 47.—Side View and Section of a Trout's Gill

the mouth is closed, each gill cover moves inwards, and the throat closes. This forces the water out of the reduced mouth cavity through the gill openings. Only a very thin membrane separates the water, as it passes over the gill filaments, from the blood which is inside them, and an interchange of dissolved gases takes place, oxygen going from the water to the blood and carbon dioxide from the blood to the water.

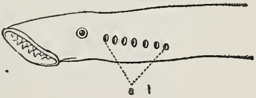

Fig. 48.—Gill Openings of Eel

Frogs belong to a class of animals called *amphibians;* that is to say, they begin life as water-breathers but later change into air-breathing animals. In consequence their organs of respiration alter with the change of environment. The first stage of a frog's existence is spent as a tadpole or "polly-

wog", and it cannot live out of the water. During this period its respiration is accomplished by means of gills. When born, the young tadpole has two pairs of frontal gills on each side of the head. Soon another pair of similar gills appears alongside the original pairs. These are the *external gills*. Between the external gills are the *gill clefts* opening into the mouth cavity. These external gills are plentifully supplied with blood vessels, and the required exchange of dissolved gases between the water and the blood takes place within them. Soon, however, the external gills disappear, and their place is taken by *internal gills* which are covered by the flap of skin called the *operculum*. This flap grows from the back of the head over the gills and encloses a gill chamber. In the meantime the tadpole has grown a mouth. Water is now taken in at the mouth and passes through the gill chamber where the exchange of gases takes place. The water passes out of the chamber through an opening on the left side called a *spiracle*. Later, as the tadpole changes into the adult frog, these gills shrivel up and a simple form of lung takes their place. During this period of change the tadpole frequently comes to the surface for air. The developing lungs are used more and more and the gills less and less. Finally they disappear and the creature has changed from a water-breathing into an air-breathing animal. It is now an adult frog in everything but size.

**The Respiratory Adaptations of the Frog**

In the adult stage the frog has three organs of breathing, the lungs, the mouth, and the skin.

The lungs of the frog are very primitive affairs when compared with human lungs. They are simple sacs, having their internal surfaces somewhat in-

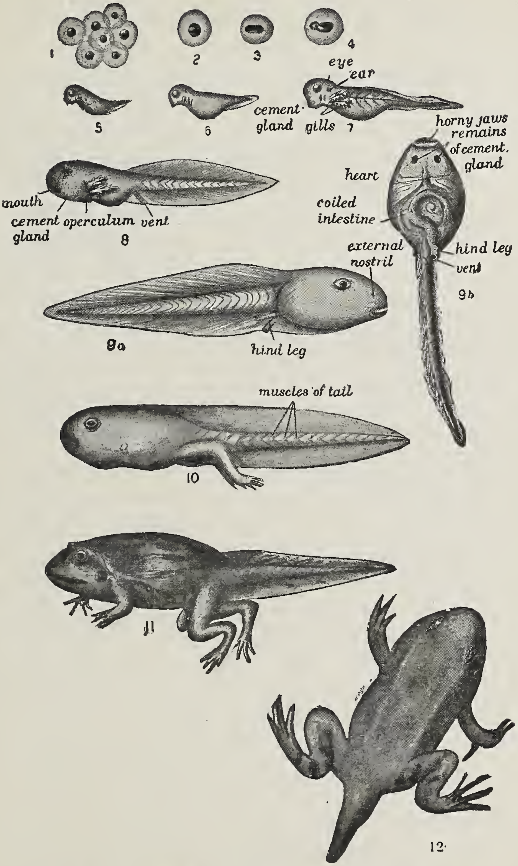


**Fig. 49.—Stages in Development of the Frog**

creased by foldings of the skin, which is very thin and well covered with blood vessels. In breathing, frogs cannot inhale the air like human beings. This is because they have neither ribs nor diaphragm. They have to push the air into the lungs. This they do by opening their nostrils and at the same time lowering the floor of the mouth. Air now rushes into the enlarged cavity. Next the nostrils are closed and the floor of the mouth is raised. This forces the air down into the lungs. Exhalation takes place by the elastic return of the lungs and the pressure of the other internal organs on them, as soon as the nostrils are opened. In order to supplement the respiration afforded by these simple lungs the inside of the mouth is well provided with blood capillaries, and an exchange of gases takes place in the mouth of a frog as well as in its lungs, thus making the mouth a supplementary breathing organ.

In addition, the skin of a frog is moist and is very richly supplied with blood vessels. A very considerable amount of gaseous exchange is carried on through the skin. So important is the breathing respiration of the frog that, if the skin becomes too dry to permit it, the animal dies of suffocation. All through the long winters frogs sleep under the leafy mould of the forests, or they are buried in the mud at the bottom of streams, ponds and marshes. During this period they breathe through the skin alone.

**The Respiratory Adaptations of Birds**

Birds are very active creatures. Their normal body temperature is 104 degrees F., which is higher than that of any other animal. This high body temperature and the great activity of birds demand a very efficient breathing system, in order that the rate of oxidation may be proportionately increased. The

respiratory system of birds has the most efficient breathing apparatus known among animals possessing a backbone. The possession of lung sacs and air spaces in some of the bones, in addition to the lungs, is the most important breathing adaptation of the birds. A bird's lungs are attached to the backbone and ribs and are connected to the mouth cavity by a windpipe or *trachea.*

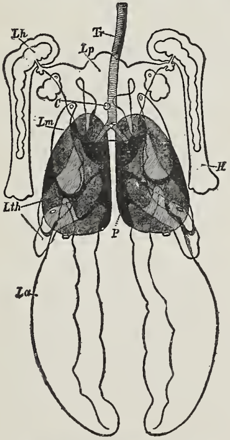


**Fig. 50.—Position of Lungs and Air Sacs (Pigeon)**
*Tr*, windpipe; *P*, lungs; *Lm*, sac under clavicle with prolongation (*Lh*) into humerus; *La*, sacs in abdomen.

Connected with the lungs are several transparent membrane bags, called *lung sacs.* Some of these lung sacs lie on either side of the heart region; others extend into the abdomen. In some birds they are continued into the hollow bones of the wings and thighs. The air is drawn through the nostrils into the mouth cavity and down the trachea into the lungs, but some of it passes through into the lung sacs, which can be distended with air at the will of the bird. In some way, not yet properly understood, the air of the lung sacs is utilized in respiration, thus securing a more perfect oxidation of the blood.

**Respiratory Adaptations of Man**

In man, as in all mammals, the organs of breathing are the lungs. It must be clearly understood, however, that the actual respiration, that is, the oxidation of food materials, goes on in every cell of the body. The lungs are simply the organs by which

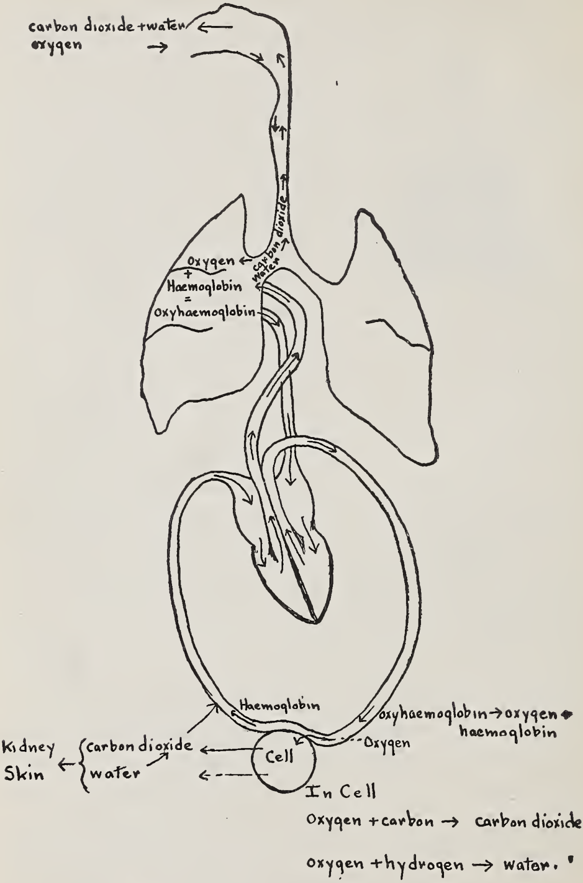


Fig. 51.—Oxidation in the Body

fresh air is taken into the blood and the impure air expelled. The lungs are two spongy, bag-like masses consisting of a complicated network of air tubes and cells, blood vessels, and elastic tissue. They occupy nearly all of the chest chamber. The air tubes and cells of the lungs are connected with the nose and mouth chambers by a strong tube called the windpipe or *trachea*. The blood vessels are connected with the heart by means of the *pulmonary artery* and the *pulmonary vein*. In breathing, the action of the diaphragm and the rib muscles alternately enlarges and contracts the chest chamber. When the diaphragm is bent down the chest is enlarged, and air passes through the nostrils into the windpipe and thence into the air tubes and cells of the lungs. This action is called *inhalation*. When the diaphragm reverses its position and is bent upwards, the chest is contracted and some air is forced out. It is important to remember that these actions never completely empty the lungs of air. Hence we have on one side of the thin walls of the air

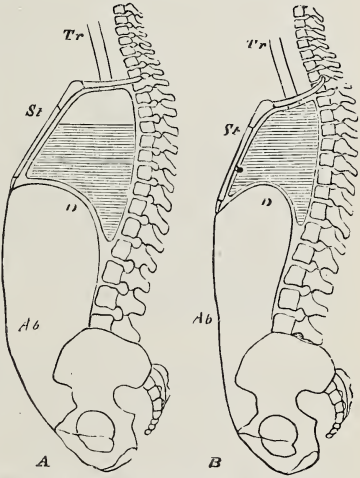


**Fig. 52.—Diagrammatic Sections of the Body: in A, inspiration; B, expiration; Tr, trachea; St, sternum; D, diaphragm; Ab, abdominal walls.**
**The shading roughly indicates the stationary air.**

cells hot blood containing carbon dioxide gas, and on the other, air containing oxygen. An exchange of these gases takes place, the air parting with some of its oxygen, and the blood at the same time giving up its carbon dioxide and some water. The action of *exhalation* clears out some of these impurities and the act of inspiration draws in fresh supplies of oxygen. While all this is going on the pumping action of the heart drives the oxygen-laden blood forward, replacing it with blood laden with carbon dioxide for purification. A healthy adult breathes about 18 times a minute, children about 25 to 30 times, and an infant about 40 times a minute. It has been estimated that about 350 cubic feet of air are inspired and expired by an average adult while at rest, in 24 hours.

**Differences Between Inhaled and Exhaled Air**

Exhaled air differs considerably from that which is inhaled. Good fresh air normally contains about 79 per cent. of nitrogen, 21 per cent. of oxygen, and .04 per cent. of carbon dioxide with varying quantities of water vapour. The exhaled air contains 79 per cent. of nitrogen, about 16 per cent. of oxygen, and about 4 per cent. of carbon dioxide. It is always saturated with water vapour and contains varying amounts of decaying organic matter. The temperature of exhaled air from human beings is 97 degrees F. We may summarize the air changes during respiration, therefore, as follows:

1. Oxygen is diminished about one-fourth.
2. Carbon dioxide is increased about one hundred times.
3. Water vapour is greatly increased.
4. Ammonia and organic matter are increased.

It is the presence of these poisonous organic wastes

which makes exhaled air so dangerous to breathe. The following experiments will show that exhaled air contains more carbon dioxide and water than fresh air and is of a constant temperature.

**Experiment 36.**—*To find out if exhaled air contains more carbon dioxide than inhaled air.*

Set up an apparatus as in Fig. 53. See that the corks are air-tight. Put some fresh limewater into each bottle. Next suck at the tube marked C. This draws air through the limewater in the bottle marked A. Notice what happens. Next blow through C. This forces air from your lungs through the limewater in the bottle marked B. Now compare the limewater in each bottle. What difference do you notice? How can you account for this difference? Which contains the greater quantity of CO , inhaled or exhaled air?

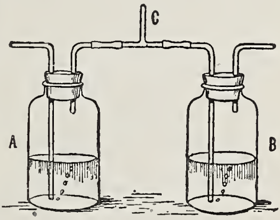


**Fig. 53.—Air drawn into A does not turn limewater milky, but when blown through C from the lungs the limewater in B is turned milky**

**Experiment 37.**—*To find out if exhaled air contains more moisture than inhaled air.*

*Procedure:* Carefully polish the surface of a mirror. Hold the mirror in the air. Do you notice any dimming of the surface? Now breathe on the mirror. What do you see now?

How do you account for the difference?

**Experiment 38.**—*To show that the temperature of exhaled air is constant.*

*Procedure:* Place a thermometer close to the mouth, but without touching it. Breathe on it for a considerable time. Note the temperature. Exhaled air is always of a temperature of about 97 degrees F.

How can you account for this steadiness of the temperature?

**Animal Heat and Energy**

In the present chapter we have been studying the various methods by which animals secure their oxygen. We must now consider the use which is made of the oxygen thus obtained.

When the oxygen reaches the cells of the animal's body it combines with the carbon and hydrogen ob-

tained from the food; that is, *oxidation* takes place producing carbon dioxide and water and liberating heat. Now whenever oxidation occurs without producing flame or light, *slow combustion* is said to take place. The respiration of animals, then, is a form of slow combustion, by which the body maintains its heat and secures the necessary energy to carry on its work.

In this respect we may consider that an animal's body is a very complex machine for using and transforming heat energy, which it produces by a form of *slow internal combustion.*

## QUESTIONS

1. What are the essential conditions for the germination of seeds?
2. What beneficial effects on the growth of plants are afforded by securing aeration of the soil?
3. Why is oxygen such a valuable substance in the air from the standpoints of (a) fires, (b) plant life, (c) animal life?
4. What is respiration? Describe an experiment which clearly shows that plants respire.
5. What are the "lenticels" of a plant? Where are they found and what is their function?
6. Why cannot plants thrive in dusty or smoky situations?
7. What special adaptations of their structure or method of growth make it possible for certain plants (e.g. cypress) to grow in swamps?
8. How do the simpler plants and animals obtain oxygen for respiration?
9. In what important ways does plant respiration differ from animal respiration?
10. What is the difference between respiration and breathing?
11. Classify the breathing adaptations of animals and mention a typical animal of each class.
12. In what important respect does the respiration of insects differ from that of any other class of animal life?
13. Describe three ways in which aquatic insects have become adapted for respiration in a water environment.
14. Why cannot fishes live in water that has been boiled for a considerable time and allowed to cool without being agitated?
15. Describe the breathing adaptations of an oyster.
16. How do fishes respire?

17. Describe the evolution of the respiratory organs of a frog, from the tadpole to the adult stage.

18. What extra respiratory adaptations do birds possess and why do they need them?

19. Why do earthworms come to the surface of the ground during a heavy rainfall?

20. Describe the process of oxidation in the human body.

21. Mention four important differences between inhaled and exhaled air caused by human respiration.

# CHAPTER X

## VENTILATION

The breathing of impure air produces immediate and very marked ill effects on the body. We experience drowsiness, lack of attention, headache, faintness, and generally unpleasant feelings in crowded, overheated rooms, lecture halls and places of amusement. These are the result of breathing the impure air of such places.

**Bad Effects of Breathing Impure Air**

But, bad as they are, these sudden effects are not so injurious as those which are gradually experienced by persons who spend their days in hot, poorly-ventilated offices and workshops, and their nights in small, stuffy rooms. Under such conditions the air is breathed and rebreathed, until not only is the blood deprived of the necessary oxygen, but poisons are definitely added to it. Continued breathing of such impure air greatly weakens the general health, and increases the tendency to take chills. The consequent lowered vitality of the body also leaves such persons predisposed to disease.

Air may be rendered impure and dangerous to those breathing it in the following ways:

1. By overcrowding.
2. By gas, open coke, or other fires.
3. By defective drains.
4. By general dirtiness of clothing, house or furniture.

5. By injurious matters given off by factories.
6. By lack of ventilation.

**Quantity of Air Required by a Healthy Adult**

If we are to escape the ill effects of breathing impure air, it is plain that the air of our buildings must be changed frequently. The question at once arises, how often should this be done? It is stated by competent authorities that every adult person requires not less than three thousand cubic feet of air per hour, in order to maintain the highest standard of health. Let us see what that means. A room measuring ten feet each way represents a space of 1,000 cubic feet. Such a room would be properly ventilated for one person if the air were completely changed every twenty minutes. If a fire or one or two gas burners were used in the room, the air would require changing much more frequently—in fact not less than six times.

*The art of ventilation* requires the making of these changes without producing unpleasant draughts or unduly lowering the temperature of the room. *Ventilation* is spoken of as either *natural* or *artificial.* By the former is understood all ventilating methods which do not require complicated mechanical devices to secure the change of air.

Most dwelling houses and other buildings are ventilated by the natural method. Unfortunately, when many of our buildings are planned, no special provision is made for ventilation, so we have to secure it as best we can. All forms of natural ventilation depend upon the fact that when air is heated it expands. Therefore, any given mass of heated air is less dense than a similar mass of cooler air. The warmer air tends to rise and become replaced by a cooler and heavier volume of air from other sources.

As our houses are usually of a different temperature from that prevailing outside, this natural behaviour of air is made use of in ventilating them. In the winter, the air inside an occupied house is so much higher in temperature than the air out of doors, that there is always a tendency for air from the outside to rush in and displace the impure air inside. Hence, by providing inlets for the cooler air outside and outlets for the warmer and impure inside air, ventilation may be carried on quite efficiently. The most convenient manner of providing these inlets and outlets is by opening the windows of a room at both top and bottom.

Open windows are, without a doubt, the best and simplest means of ventilating a room. The principal objection to ventilating by means of windows is that this creates draughts. These may be overcome by several simple devices. One excellent way is to fit the lower opening with a frame covered with ordinary cotton cloth, somewhat like a mosquito screen. The meshes of the cloth allow free passage of air without creating a draught.

It is important to remember, when using windows to ventilate a room, that opening a window a little at both top and bottom is far better than to open one sash fully. In the summer months when the difference between the indoor and outdoor temperature is not so marked, the ventilation is not so effective and additional openings are necessary. It is sometimes necessary to assist the circulation of the air at these times by the use of a small fan.

**Artificial Systems of Ventilation**

In large buildings such as schools, hospitals, factories, and on large ships, efficient ventilation by natural means is often impossible. In

such cases artificial or mechanical ventilation is used. All artificial systems of ventilation fall into two distinct classes.

1. The *propulsion system,* also called the *plenum* or *pressure* system.

2. The *aspiration system,* sometimes referred to as the *exhaust, vacuum,* or *extraction* method.

In ventilating by the propulsion method air is forced into the building by means of bellows, pumps or fans. The incoming air is usually filtered and warmed. The amount of moisture it contains is also carefully controlled. The impure air is forced out by the pressure of the incoming air, and is allowed to escape through special openings. The great advantage of the propulsion system lies in the excellent control obtained over the condition and speed of the incoming air. The main disadvantage lies in the tendency of the incoming air pressure to force the foul air into corners whence it is not easily removed, so that the air in the building is often neither properly renewed nor diffused.

The aspiration system of ventilation draws the impure air out while the fresh air enters through openings in the basement, or sometimes as best it may through the window joints or under the doors. The air may be drawn out in several ways. Sometimes a suction fan is placed in a chamber above the ceiling of the topmost story. At other times a large shaft or flue is constructed which rises above the roof of the building as a tower or cupola. Heat, in the form of a fire or steam jet, is applied at the foot of the shaft. This causes a powerful up-draught by which air is drawn from the rooms. As the air is removed, the pressure inside the building lessens, and the greater pressure out of doors forces fresh air in through the

special intakes. This pure air is then allowed to enter the rooms through fresh-air registers placed near the floor levels.

The disadvantages of the aspiration system are:

1. The source of the incoming air cannot be controlled.

2. It is difficult to regulate the incoming air and to prevent draughts.

The principal advantage of the system is that the impure air is constantly, gradually, and thoroughly removed.

*Artificial or mechanical ventilation* has several points of superiority over *natural ventilation.* These may be summarized:

1. It is independent of the weather.
2. Draughts are usually avoided.
3. Heating and ventilation are more efficient.

On the other hand mechanical systems are expensive to install, maintain, and operate.

**Ventilation of Schools**

Since a school has to accommodate a considerable number of persons, the pollution of its atmosphere is very rapid. This means that the air of a classroom must be changed at a rather rapid rate, if the students are to be healthy and alert.

Most modern schools, therefore, are equipped with one or other of the mechanical ventilating systems just described. In smaller schools, where such an expensive installation would be out of the question, the heating system is arranged in such a manner that it promotes the circulation of the air, thus securing good ventilation conditions.

The efficient ventilation of buildings used to house animals is a matter of great importance. Too often the ventilation of such places is left to take care of

itself. Under such conditions the barns become draughty and cold, or else stuffy and smelly. The result is that the animals in them become inefficient and, all too often, are so lowered in general health as to fall easy victims to disease.

**Ventilation of Stables**

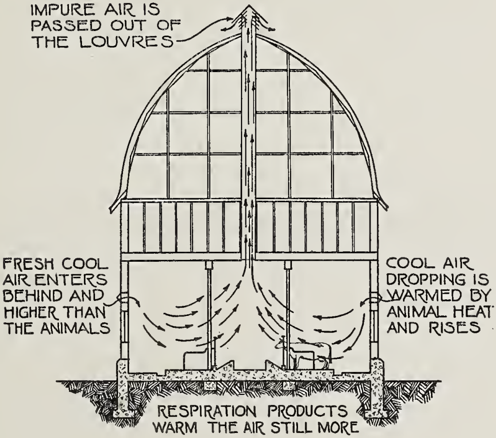


**Fig. 54.—Ventilation of Stables**

Good farmers, therefore, pay great attention to the ventilating conditions of their animal barns. All stables are ventilated by the natural method. Sometimes, however, simple devices like globe ventilators in the roof are used to assist the natural currents. The general practice in stable ventilation is to allow the fresh, cold and therefore heavier air from the outside to enter the building behind the animal, through openings placed so as to be higher than their bodies.

This heavier cool air tends to fall to the floor, and in falling is warmed somewhat and tends to rise again.

As it approaches the animals their body heat warms it even more, causing it to rise again. Some of this air is breathed by the animals and becomes still warmer. The result is that the air near the animals' heads is much warmer than that to the rear of them. This warmed and polluted air rises to the ceiling where it is allowed to escape through shafts connected with louvres, or globe ventilators, placed on the ridge of the barn.

**Ventilation of Mines**

There are several reasons why the proper ventilation of mines is a very important consideration.

1. The breathing of the men and animals underground, together with the burning of illuminants in the confined spaces of a mine, quickly renders the air impure.

2. The large quantities of dust produced by the nature of the operations is very dangerous to health, and in the case of coal mines this dust is highly explosive.

3. The blasting operations fill the air with poisonous gases.

4. In the case of coal mines, the coal gives out quantities of gases, which are often explosive. Even when not explosive such gases are injurious.

It therefore becomes necessary to keep a vigorous current of cool, fresh air circulating through the mine. All wise governments realize this and insist that there shall be an efficient system of ventilation in mines. Even if governments do not do this, it pays the owners of a mine to secure good ventilation, for under good ventilation conditions the men are able to work with greater comfort and contentment, and so accomplish more work.

In every case of mine ventilation there must be provided:

1. Two shafts or outlets to the mine. Fresh air enters through one called the "downcast". Impure air leaves by the other which is called the "upcast".

2. Underground connection between them.

3. Some means of setting the underground air in motion. This motion may be produced by natural heat, falling water, steam jets, furnaces, or fans.

*Natural ventilation of mines* may be obtained when there is a difference in the length of the downcast and the upcast, and also a difference in the temperature of the two columns of air.

In naturally ventilated mines, this difference in temperature is due to the heat given off by the rocks and from the men and animals working below ground. This warming of the air causes it to rise to the surface by way of the upcast. The amount of air changed depends on the changes in temperature at the surface. In winter and summer the air exchanges would be greater than in the spring and fall. For this reason, natural ventilation is not often used in the ventilating of gassy coal mines, where the inflammable and dangerous gases must be regularly and rapidly removed. Such mines use some form of artificial ventilation. The oldest method is that of artifically altering the density of the air within the upcast shaft by heating it. This is called furnace ventilation. The furnaces are placed at the bottom of the upcast, and are usually constructed of brick with air chambers on either side so as not to overheat the strata. The heated air passing over the furnace enters the upcast and, being lighter than the cooler air in the downcast, is therefore pushed upward.

*Ventilation by fan* is the method most commonly

used in modern coal mines, because by this means the rate of circulation can readily be varied to suit changing conditions. Some fans force the fresh air down into the mine, while other installations make use of exhaust fans which draw the air out of the mine.

The production of the air current is really the simplest part of the problem of efficiently ventilating a mine. More difficult is the proper distribution of the air currents to every nook and corner of the mine. This distribution is managed by making the air travel along air ways. Its direction, speed and volume are controlled by a complicated system of air-crossings, doors, sheets, and other regulators.

## QUESTIONS

1. What are the effects on the body of breathing impure air?
2. On what principle does natural ventilation depend? How may ordinary sash windows be used to ventilate rooms properly?
3. Describe some simple methods of ventilating rooms. Illustrate your answer by sketches.
4. What is understood by the term ventilation?
5. How is air rendered impure by the process of respiration? How many persons should be allowed to sleep in a room 12 feet long, 8 feet wide and 10 feet high under ordinary conditions of window ventilation?
6. What is meant by artificial ventilation? Contrast the advantages and disadvantages of the two types of artificial ventilation.
7. What are the chief difficulties in efficiently ventilating a school class room and why? How is ventilation usually secured in a large city school?
8. Why should farmers pay careful attention to the ventilation of their animal barns?
9. How are modern stables usually ventilated?
10. Name three essential features of mine ventilation.

# CHAPTER XI

## NATURAL IMPORTANCE OF NITROGEN AND CARBON DIOXIDE

**The Importance of Nitrogen**

*Nitrogen,* the inactive part of our atmosphere, is of extraordinary importance to man. In the first place, the presence of such a large quantity of inactive material acts as a damper on the activities of the oxygen. In an atmosphere of pure oxygen combustion of all kinds would be so violent, that life in it, if at all possible, would be very different from that which we now enjoy. In the second place, nitrogen is the essential element of innumerable drugs, medicines, dyes, explosives, fabrics, varnishes, and other materials used in our modern civilization. Lastly, but most important of all, every living thing, be it plant or animal, requires nitrogen. Deprive animals or plants of food containing nitrogen, and they quickly sicken, fade, and die.

It is one of the most remarkable facts of nature that, though living things depend on nitrogen, not one single animal and only a few kinds of plants can make direct use of the enormous amount of free nitrogen in the air. This is because nitrogen must be combined with other substances before it can be assimilated as plant or animal food. This act of combining the free nitrogen of the air with other substances so as to produce food stuffs is called the *fixation of nitrogen,* and the nitrogen held in such compounds is called fixed nitrogen.

**How Nitrogen is Lost**

Maintaining the proper quantity of fixed nitrogen in the soil is one of the great problems of agriculturists. This is because under present conditions we are removing the useful nitrogen content of our soils faster than the slow processes of nature can replace it. This excessive drain on the fixed nitrogen of the soil is, in the first place, due to the food requirements of plants, animals and human beings. The plants draw their fixed nitrogen compounds from the soil and convert them into the complex compounds called *proteins.*

Protein is the most essential constituent of *living* things. In fact, it is only the protein part of them that is really alive. Every action of a living thing is produced through the breaking up of these complex proteins into simpler nitrogen compounds within the various tissues of its body. These smashed-up proteins are passed out of animal bodies as perspiration and excreta. Man and animals replace them by eating protein-bearing foods like meat, eggs, fish, beans and peas. Every animal is absolutely dependent, either directly or indirectly, on plants for its supplies of protein-bearing food. The plants in turn depend entirely on the soil for almost every trace of nitrogen which they contain. The soil, in its turn, won this nitrogen from the air by extremely slow processes.

The second important drain on the fixed nitrogen of the soils is due to the many uses man makes of nitrogen in his industries, amusements, sports and wars. Thus we see that every crop the farmer takes from the fields, every photograph that is taken, every motion picture that is produced, many of our most beautiful dyes, all the "Duco" finishes of our automobiles, and a thousand

and one other things, all help to drain this hardly-won store of usable nitrogen from the soil.

The result of all this is that farm soils get run down. Every one knows what must be done to such soils. They must be fertilized. This is done by introducing into them substances containing fixed nitrogen which plants can utilize in building up their proteins.

There are several ways in which fixed nitrogen may be introduced into a soil. They may be divided into two great classes, namely, *Natural Methods* and *Artificial Methods.*

**How Nitrogen is Introduced**

There are four natural ways in which fixed nitrogen may be introduced into soils:


*Courtesy College of Agriculture, University of Illinois*

**Fig. 55.—Relation of Nitrogen to Soil Fertility**

On the left, a complete fertilizer was used, but no soil bacteria were present; on the right, soil bacteria supplied the nitrogen; in centre, plants had no nitrogen and no soil bacteria.

1. By the growing of leguminous plants, like peas, beans, clovers, and lupines. These plants do not really fix the atmospheric nitrogen. This work is actually done by colonies of nitrogen-fixing bacteria that live

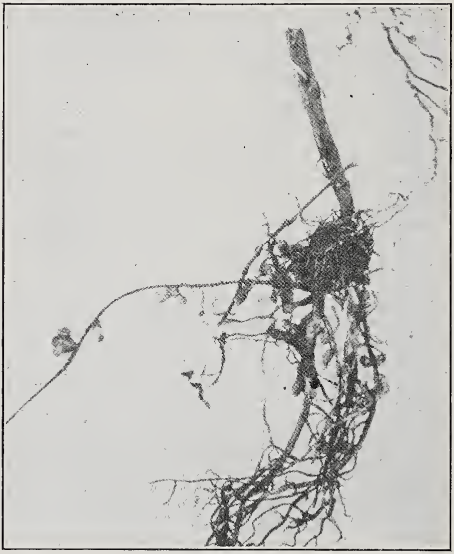

Fig. 56.—Nitrogen-fixing Bacteria on Roots of Clover

in tiny nodules about the roots of leguminous plants. These nodules can easily be seen as white balls clinging to the roots of the common white, or Dutch, clover.

2. By the decay of animal and vegetable matter. This is what happens when barnyard manure is put into the soil.

3. By lightning flashes during a thunderstorm. Lightning is simply an electric discharge. Such discharges cause small amounts of atmospheric oxygen

to produce oxides of nitrogen. These are washed by the rain into the soil, where they combine with certain parts of the soil and are utilized by the plant.

4. Ammonia gas is dissolved by the falling rain and carried into the soil, when it is available to the plant once more.

These natural methods, supplemented by the use of barnyard manures, were sufficient until quite recent times. To-day, however, owing to the great increase in population, its concentration in manufacturing districts, and the ever-increasing demands of modern industry, such methods no longer suffice. As a result scientists have established a new chemical industry which is devoted to the manufacture of fertilizing materials. This industry manufactures fertilizers from the wastes of packing plants, fish and fish wastes, the refuse of the vegetable-oil extraction plants, and from the by-products of coal gas manufacture.

In addition, the vast natural nitrates locked up in the deposits of guano from rainless tropical islands, and the great beds of natural nitrate of soda from the Atacama Desert of Chile, are made to yield their precious stores of nitrogen.

**Artificial Fixation of Nitrogen**

In 1898, Sir William Crookes startled the world by calling attention to the probable early exhaustion of the Chilean nitrate deposits, and the effect it would have on the production of wheat. This resulted in scientists attempting the *artificial fixation of nitrogen.* Success has crowned their efforts, and to-day there are several processes by which electricity is used for this purpose. The credit for the first successful process belongs to two Norwegians, Birkeland and Eyde.

One of the largest industrial chemical plants in

Canada is the Cyanamide Factory at Niagara Falls, Ontario, where a nitrogen fertilizer called *cyanamide* is produced by the electrical fixation of atmospheric nitrogen.

The tremendous importance of increasing the rate of nitrification in soils has also resulted in the discovery of another method of artificial fixation. For a long time, it was thought that the nitrifying bacteria would live only on leguminous plants. Professor Bottomley, however, showed that they could be made to work with other plants. Then scientists were thrilled with the possibility of inoculating poor soils with nitrifying bacteria. In 1896, a microbe, in portable form, was put on the market under the name of "Nitragin". To-day, after many failures, the success of such portable forms of nitrifying microbes has been so great that they are being produced on a large scale. At present they are used in many parts of Western Canada to prepare land for the introduction of sweet clovers and alfalfa.

**The Nitrogen Cycle**

Nitrogen is constantly passing and repassing through a definite succession of natural changes. First, the bacteria, which live at the roots of the leguminous plants, withdraw some of the *free nitrogen* from the atmosphere and convert it into nitric acid. The lightning discharges during electric storms also convert some *free nitrogen* into nitric acid. The nitric acid so produced combines with certain mineral components of the soil forming *nitrates.* These nitrates, being soluble in water, pass into the plants through the root hairs. In plants they are changed into *proteins.* The plants are, in turn, eaten by animals and the proteins are converted into animal *protoplasm* or *cell materials.* During the life of both plants and ani-

mals, these cell materials are constantly breaking down into simpler materials. This incessant breaking down of cell material releases some of the nitrogen, which is returned to the atmosphere. At the death of

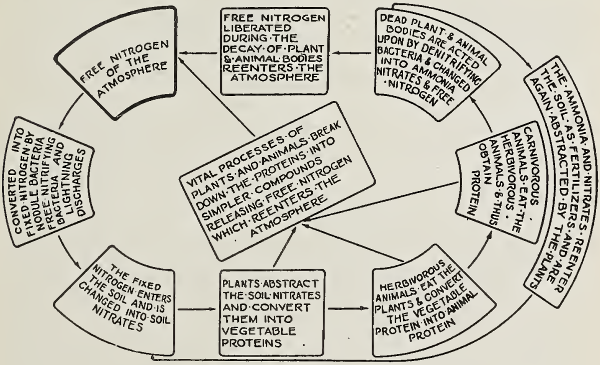


Fig. 57.—Nitrogen Cycle

a plant or animal, the slow decomposition of their tissues returns simple nitrogenous compounds to the soil as *humus,* and as *free nitrogen* to the atmosphere, and so the cycle begins again. This succession of events is known as the *Nitrogen Cycle.* It is but one of several similar cycles by which nature maintains the succession of life on the earth.

**Carbon Dioxide**

The proportion of this gas present in the atmosphere is quite small, being only about four parts in every ten thousand. It finds its way into the atmosphere by five principal channels:

1. By the respiration of plants and animals.

2. By the combustion of materials containing carbon.

3. By the decay of plant and animal matter.
4. By the germination of seeds.
5. From the mouths of volcanoes and through rock fissures in volcanic regions.

We must not let the small proportion of carbon dioxide present in the atmosphere make us think of it as an unimportant component. On the contrary, carbon dioxide is one of the most important gases of the air. Every single tissue of the bodies of plants and animals, from the lowest to the highest, is built up of substances containing large proportions of carbon. All this carbon is derived from the carbon dioxide of the atmosphere. In addition, all the carbon of our coals, gasoline, coal oil and natural gas, as well as in the huge beds of limestone in many of our mountain ranges, has been extracted from the carbon dioxide of the air.

**Relation of Carbon Dioxide to Plants**

Water and carbon dioxide are the two principal raw materials used by plants in manufacturing their food. In addition, they require nitrogen and some mineral substances. The water is obtained from the soil, as, also, is the mineral matter. We have seen that the nitrogen required by plants must be withdrawn from the air and *fixed* in the soil before the plant can use it. The carbon dioxide is obtained directly from the air.

The process by which plants obtain carbon dioxide from the air and manufacture it into food is called photosynthesis. This process can only be carried on by plants containing the green substance called *chlorophyll,* and then only in sunlight. Plants which contain no chlorophyll, and consequently have no green tissues, cannot manufacture food. They must secure it from either the dead or living bodies of other plants. Be-

cause of this inability to make their own food, they are called dependent plants. If they get their food by attaching themselves to living plants or animals, they are called *parasites*. When they feed on decaying plant and animal matter, they are called *saprophytes*. Dodder, rust, and mildews are parasitic plants. Mushrooms, mould on bread and cheese, and Indian Pipe are saprophytic plants.

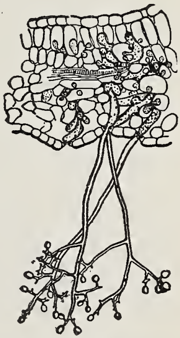

**Fig. 58.—A Parasitic Fungus, magnified**

*Photosynthesis*, or the manufacture of sugar and starch by the aid of sunlight and chlorophyll, takes place principally in the leaves of the plant. In fact, we may consider the leaf of a green plant as a workshop or factory specially designed for this purpose.

The process may be said to have three essential steps:

1. The bringing together of raw materials; namely, water from the soil, and carbon dioxide from the air.

2. Combining these together to make sugar, starch, and wastes, by the action of sunlight and chlorophyll.

3. Discharging the waste material (principally oxygen).

**Fig. 59.—Mushroom**

Example of a saprophytic plant. This is the edible cultivated mushroom.

In order to follow these steps intelligently, we must know certain things about the structure of the leaf.

**Structure of Leaves**

All leaves are similar in their general structure, though they differ considerably in details owing to changes produced by varying environment.

All leaves possess the following parts: (See Fig. 41).

1. An upper and lower layer of cells arranged horizontally, called the upper and lower epidermis.

2. The mesophyll which occupies most of the interior of the leaf. In most leaves, the mesophyll consists of two distinct types of cells:

(a) The palisade cells lying just beneath the upper epidermis. These cells are rather elongated, and are arranged vertically in one or more compact tiers.

(b) The spongy tissue, consisting of irregular cells with many air spaces among them. These cells lie just above the lower epidermis. All the cells of the mesophyll region contain many minute bodies called *chloroplasts*. These contain the green colouring matter called *chlorophyll.*

3. The conducting tissues consist of bundles of tubes, some of which convey water and minerals from the soil to the leaves, while others return the manufactured foods from the leaves to all parts of the plant. These bundles of connecting tissue also form a supporting framework for the leaf.

4. The stomata, or tiny openings in the epidermis, which are connected with the air spaces of the spongy tissue. These openings are very numerous and are usually more plentiful on the under side of the leaf. There are often 50,000 per square inch of leaf surface.

*Step* 1—*Bringing together the raw materials.* The water enters the roots of the plants through the root hairs and rises through a series of tubes in the stem of

the plant, eventually reaching the leaves through certain tubes of the connecting tissue. The carbon dioxide enters with the air through the stomata and diffuses through the air spaces of the spongy tissue. The water passes out of the tubes and fills all the cells of the mesophyll layer. Similarly the air passes through the cell walls from the air spaces, bringing the carbon dioxide and the water together.

*Step 2—Making the sugar and starch.* They are now in close contact with the chloroplasts. When the sun is shining, the water and the carbon dioxide are united, forming sugar, starch, and oxygen. Just how this is accomplished, no one quite knows. We are sure that the change is made. The sugar dissolves in the water and is carried away by a return series of tubes in the connecting tissue to all parts of the plant, as food. The sugar not immediately needed for food is converted further into starch and stored in various parts of the plant until required. A part of the sugar is conveyed to the growing layer, or cambium, of the twigs, branches, stem and roots. Here it is converted into cellulose, the material of which the woody fibres of the plant are composed.

*Step 3—Discharging the waste material.* Most of the oxygen which is produced when sugar is formed passes out through the stomata into the outside air, where it mingles with the other gases. Some of it, however, may be used by the plant in its respiration.

*Comparison of a leaf and a factory*—The leaves of a plant, or any green plant cell, are often likened to a factory in which the machinery is the chlorophyll, the energy is the sunlight, the raw materials are water and carbon dioxide, the finished products are sugar, starch and cellulose, and the waste product is oxygen.

Photosynthesis by green plants is easily the most

important process in the world, since upon it depends the food supply of every living thing. No animal is able to build up its food from simple inorganic compounds like water and carbon dioxide. The feeding of fishes and other animals inhabiting the rivers, lakes, and seas of the globe, depends upon the work of tiny chlorophyll-bearing plants called diatoms, algae and plankton, which are able to make use of this process of photosynthesis.

**Importance of Photosynthesis**

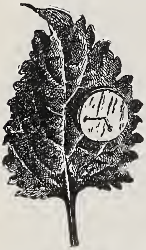

Fig. 60.—Excluding Light and $CO_2$ from Part of a Leaf

Fig. 61.—The Result

*Comparison of photosynthesis and respiration*—We have already pointed out that it is a very common error to confuse these two processes. It is important to keep clearly in mind the difference between them. These are summarized and compared in the table given below. (See also p. 119).

| PHOTOSYNTHESIS | RESPIRATION |
|---|---|
| 1. Takes place only in cells containing chlorophyll. | 1. Takes place in all living cells. |
| 2. Requires light energy. | 2. Does not depend upon light. |
| 3. Uses carbon dioxide. | 3. Uses oxygen. |
| 4. Stores energy. | 4. Releases energy. |
| 5. Liberates oxygen. | 5. Liberates carbon dioxide. |
| 6. Forms carbohydrates. | 6. Consumes carbohydrates. |
| 7. Increases weight. | 7. Decreases weight. |

**The Carbon Cycle**

From the study of the importance of carbon dioxide, we must have realized that there is a continuous circulation of carbon between the atmosphere, plants and animals. This circulation is known as the *Carbon Cycle,* and is

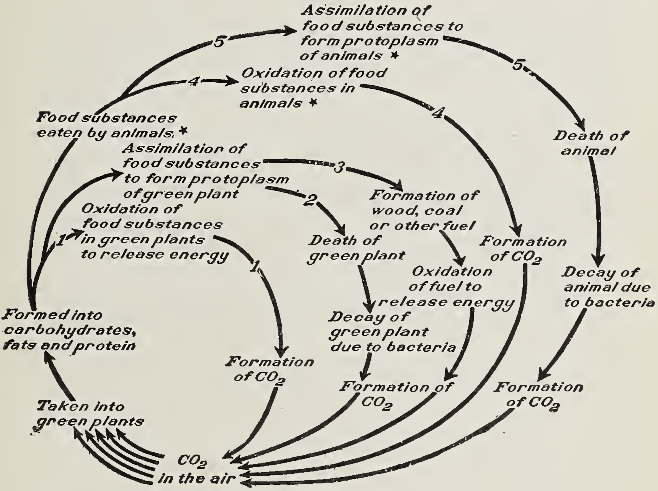


**Fig. 62. The Carbon Cycle**

Trace the carbon and oxygen in the successive cycles (1, 2, 3, 4, and 5).

another of those great natural cycles mentioned during the study of nitrogen.

Study the diagram of this important cycle until you are sure that you understand it.

## QUESTIONS

1. Why is nitrogen of such extraordinary importance to man?
2. What is the meaning of the term "fixed nitrogen"?
3. How may the nitrogen of the air be introduced into the soil in the form of fixed nitrogen?
4. Why are the natural methods of nitrogen fixation no longer sufficient to meet the needs of man?
5. What are the present main natural sources of nitrogen fertilizers?
6. Describe in your own words the processes of the nitrogen cycle.
7. Write an account of the value of carbon dioxide. Name four methods by which carbon dioxide is formed in nature.
8. Of what importance is carbon dioxide to the life of a plant? What physical property of this gas makes it available for plants?
9. How do plants obtain carbon dioxide from the air?
10. What is the difference between "parasitic" and "saprophytic" plants? What general term is applied to both these kinds of plants and why?
11. Describe the general structure of all leaves and indicate the function of each part.
12. Green leaves are often called the "food factories of the world". Explain.
13. What is photosynthesis?
14. Point out the essential differences between the processes of respiration and photosynthesis.
15. In your own words write out a description of the carbon cycle.
16. What is chlorophyll and in what parts of the plant is it found? Describe the part it plays in nature.

# CHAPTER XII

## NATURAL IMPORTANCE OF WATER VAPOUR AND DUST IN THE ATMOSPHERE

Water vapour is present in the atmosphere at all times and under all conditions. It is one of the most variable of the ordinary components of the air, and also one of the most important because of its influence on climate and vegetation, and upon our health.

**Water Vapour**

Water vapour enters the atmosphere by nine main channels:

1. The ceaseless evaporation from the surface of every pond, lake, river, sea, and ocean.
2. The evaporation of water from the soil.
3. The transpiration, or passing out of excess water, of plants.
4. The respiratory processes of animals.
5. The exhalations from the skins of animals.
6. The decay of plant and animal matter.
7. The action of volcanoes and geysers.
8. The combustion of fuels.
9. The sublimation of ice and snow.

We are already in possession of facts which make it unnecessary to discuss further the fourth, fifth, sixth and eighth sources. Of those remaining the first three and the last are the most important. Many of our everyday experiences point to *evaporation* as a source of atmospheric water vapour. For example, water exposed to the atmosphere in open vessels disappears. Wet clothes hung out to the action of the

atmosphere rapidly dry, moist soils dry out during spells of dry weather, and so on.

This quiet evaporation of water over every exposed surface of water and soil on the earth goes on every moment of the day and night. It is perhaps the most important channel by which water vapour enters our atmosphere.

*Transpiration by plants* is easily the next most important source of atmospheric water vapour. Indeed, many authorities claim that in actual practical effects it is more important than direct evaporation from bodies of water and soils. It is said that in four months an acre of cabbages will transpire about 425,000 gallons of water; a single large oak tree is believed to transpire 23,000 gallons of water during the growing season.

Another important process supplying water vapour to the atmosphere is *sublimation*, or the changing of a solid directly into a gas without passing through an intermediate liquid stage.

This is a process far more common than is generally supposed. For example, camphor sublimes readily from the solid to the gaseous stage. Its use as a germ killer depends upon this power. Again, perfumed talcum powders owe their aromatic qualities to sublimation. Now both ice and snow have this power of slowly changing directly from the solid to the gaseous state. In regions having long, severe winter seasons, a considerable proportion of water vapour enters the air by the sublimation of ice and snow.

**Experiment 39.**—*To find out if ice can pass directly from the solid to the gaseous state.*

*Procedure:* On a cold winter day, obtain a block of ice, wipe it quite dry and quickly weigh it. Place it in a suitable dish and put it outdoors in some place where it will not be disturbed. After a few days weigh it again. What do you find? Is there any moisture on it? How do you account for the result?

*Volcanoes and geysers* send large quantities of water vapour into the air. There is no difficulty in realizing that geysers and hot springs do so. That volcanoes contribute similarly is, however, not so readily seen. This, perhaps, is because it is not generally known that steam is the chief gaseous product emitted by volcanoes. Some years ago one of the minor cones of Mount Etna was estimated to have discharged 460 million gallons of water into the air during a period of one hundred days.

*What controls the amount of water vapour that can be present in the atmosphere?*—By custom, we refer to the air holding water vapour. As a matter of fact the air has nothing to do with it. The presence of water vapour in a space is entirely independent of the presence or absence of air in that space. The quantity of water which may be present depends entirely upon the *temperature* and not at all on the presence or pressure of the air. The actual amount which is present at any particular time depends upon two factors:

1. The temperature.
2. The opportunity of obtaining water.

*Rate of evaporation* is very variable and is affected by several conditions:

1. The temperature of both the liquid and the atmosphere. Heat always hastens evaporation; therefore, other things being equal, the higher the temperature, the more rapid the evaporation.

2. The nature of the liquid. Some liquids, such as oil, evaporate very slowly; others, like ether and gasoline, evaporate quickly. Liquids which change rapidly to gases at ordinary temperatures are called "volatile liquids".

3. The pressure upon the exposed surface of the

liquid. Evaporation is most rapid during periods of low barometric pressure.

4. The degree of saturation of the air or space above the liquid. When the amount of water vapour in the air is low, evaporation is rapid, but it gradually slackens until the saturation point is reached, when evaporation entirely ceases.

5. The rate of circulation of the air over the surface of the liquid. The faster the air is changed over a liquid the more rapid is the evaporation. This is shown by the fact that wet clothes and wet roads dry most quickly on a windy day. Also plants wilt more quickly in warm windy weather than on warm days with no wind.

6. The area of the surface of the liquid exposed to evaporation. Water in a saucer evaporates more rapidly than water in an open, narrow-mouthed bottle.

**Saturated Air**

Air containing as much water vapour as it can hold at any given time is said to be *saturated.* The slightest cooling of saturated air condenses some of the vapour into liquid water. On the other hand, if saturated air be warmed it ceases to be saturated, and if it comes into contact with a water surface, that water will commence to evaporate.

**Damp and Dry Air**

Air which is saturated or nearly saturated with water vapour feels damp. Such a condition gives rise to unpleasant body sensations. These result from the slowing down of the evaporation of moisture from the skin because the air around us is so highly saturated. Consequently we feel oppressed and uncomfortable if the temperature be warm, as for instance during a hot, steamy summer day. On the other hand, if the temperature be low and the degree

of saturation be high, we experience quite different but none the less uncomfortable body sensations. Cold, damp air being a much better heat conductor than cold, dry air, the body heat is lowered too quickly and to too great an extent, with the result that we feel cold. "Chilled to the bone" is the popular expression describing this sensation produced by highly-saturated, low-temperature air.

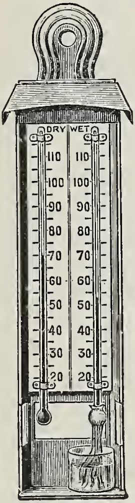

**Fig. 63.—Wet and Dry Bulb Hygrometer**

*Humidity* is the condition of the atmosphere with respect to the amount of water it contains. It is far more talked about than understood. We have seen that:

1. The amount of water vapour which can be held in the atmosphere depends entirely on the temperature of the air and on that alone.

2. The actual amount which may be present at any given time depends upon certain other conditions.

This actual amount of water present in the air at any particular instant is called the *absolute humidity.* The actual dryness or dampness of the air does not depend upon the *actual amount* of water vapour present. This condition is governed by the *proportion* of the actual amount of water vapour present to the amount the air could contain at the same temperature. This is called *relative humidity.* It is usually expressed as a percentage. Air is said to be damp when its relative humidity is 85 per cent. or more, and dry when it is 60 per cent. or less.

*How relative humidity is measured*—There are several methods of measuring relative humidity. The most convenient, and also the easiest, method is by

observing the temperature of evaporation, that is, the difference between the temperature indicated by wet and dry bulb thermometers at the same time.

**Experiment 40.**—*To determine the relative humidity from the temperature of evaporation.*

*Required:* A wet and dry bulb hygrometer. This may be purchased or it may be constructed very easily.

*Construction of a wet and dry bulb hygrometer:* Obtain two simple mercury thermometers; support them in a vertical position in any convenient manner. Under one of them place a small vessel containing water. Take a strip of linen or muslin and thoroughly wet it. Wrap one end of the wet rag round the end of the bulb of the thermometer and allow the other end to dip into the vessel of water below. Capillary action will now keep the wrapped bulb constantly moist. You now have a wet and dry bulb hygrometer.

*Procedure:* With a piece of stiff paper fan the bulbs of the thermometers until the mercury of the wet bulb thermometer ceases to fall.

This shows that evaporation is no longer taking place. This temperature is that at which the atmosphere is saturated with moisture. Now read the dry bulb thermometer.

The relative humidity is now read off as a percentage by comparison with the following table.

TABLE GIVING RELATIVE HUMIDITY

| Reading of Dry Thermometer (Fahr.) | READING OF WET THERMOMETER (FAHR.) | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 70 | 69 | 68 | 67 | 66 | 65 | 64 | 63 | 62 | 61 | 60 | 59 | 58 | 57 | 56 | 55 | 54 | 53 |
| 80 | 61 | 57 | 54 | 51 | 47 | 44 | 41 | 38 | | | | | | | | | | |
| 79 | 63 | 60 | 57 | 54 | 50 | 47 | 44 | 41 | 37 | | | | | | | | | |
| 78 | 67 | 64 | 60 | 57 | 53 | 50 | 46 | 43 | 40 | 37 | | | | | | | | |
| 77 | 71 | 67 | 63 | 60 | 56 | 52 | 49 | 46 | 42 | 39 | 36 | | | | | | | |
| 76 | 74 | 70 | 67 | 63 | 59 | 55 | 52 | 48 | 45 | 42 | 38 | 35 | | | | | | |
| 75 | 78 | 74 | 70 | 66 | 63 | 59 | 55 | 51 | 48 | 44 | 40 | 38 | 34 | | | | | |
| 74 | 82 | 78 | 74 | 70 | 66 | 62 | 58 | 54 | 51 | 47 | 43 | 40 | 37 | 34 | | | | |
| 73 | 86 | 82 | 78 | 73 | 69 | 65 | 61 | 58 | 54 | 50 | 46 | 43 | 40 | 36 | 33 | | | |
| 72 | 91 | 86 | 82 | 78 | 73 | 69 | 65 | 61 | 57 | 53 | 49 | 46 | 42 | 39 | 35 | 32 | | |
| 71 | 95 | 90 | 86 | 82 | 77 | 73 | 69 | 64 | 60 | 56 | 53 | 49 | 45 | 41 | 38 | 34 | 31 | |
| 70 | | 95 | 90 | 86 | 81 | 77 | 72 | 68 | 64 | 60 | 56 | 52 | 48 | 44 | 40 | 37 | 33 | 30 |
| 69 | | | 95 | 90 | 86 | 81 | 77 | 72 | 68 | 64 | 59 | 55 | 51 | 47 | 44 | 40 | 36 | 32 |
| 68 | | | | 95 | 90 | 85 | 81 | 76 | 72 | 67 | 63 | 59 | 55 | 51 | 47 | 43 | 39 | 35 |
| 67 | | | | | 95 | 90 | 85 | 80 | 76 | 71 | 67 | 62 | 58 | 54 | 50 | 46 | 42 | 38 |
| 66 | | | | | | 95 | 90 | 85 | 80 | 76 | 71 | 66 | 62 | 58 | 53 | 49 | 45 | 41 |
| 65 | | | | | | | 95 | 90 | 85 | 80 | 75 | 70 | 66 | 62 | 57 | 53 | 48 | 44 |
| 64 | | | | | | | | 95 | 90 | 85 | 79 | 75 | 70 | 66 | 61 | 56 | 52 | 48 |
| 63 | | | | | | | | | 95 | 90 | 84 | 79 | 74 | 70 | 65 | 60 | 56 | 51 |
| 62 | | | | | | | | | | 94 | 89 | 84 | 79 | 74 | 69 | 64 | 60 | 55 |
| 61 | | | | | | | | | | | 94 | 89 | 84 | 79 | 74 | 68 | 64 | 59 |
| 60 | | | | | | | | | | | | 94 | 89 | 84 | 78 | 73 | 68 | 63 |

*Example:* On a certain day the dry bulb thermometer reads 72° F. and the wet bulb reads 66° F. What is the relative humidity?

Find 72 in the first column on the left hand side in the table p. 168. Reading horizontally along the top line, find 66. The number where these two meet is 73. This is the relative humidity expressed as a percentage.

**Humidity and Health**

The humidity of the atmosphere exerts a very great influence on health. The effects produced, however, vary greatly with the temperature. In general it may be said that, if the humidity in our homes falls below 35 per cent. or rises above 90 per cent., conditions arise which are dangerous to health. Very careful research by the medical profession has shown that a temperature of 68° F. with a relative humidity of 65 per cent. is most favourable to health and comfort.

These conditions are seldom attained in our buildings. In winter the air out of doors may have a high relative humidity, but this does not necessarily mean that it contains a large amount of water vapour. Remember that dryness or dampness of the atmosphere is relative. Now when such air is warmed in our buildings, its moisture-holding capacity is increased. If extra moisture is not added its relative humidity falls rapidly. This results in a hot and dry atmosphere. Such an environment is not healthy. People inhabiting such rooms sleep poorly, suffer from headaches and are very susceptible to colds. They are also nervous and irritable. In addition the hot air increases the evaporation from the skin, causing such persons to feel chilly, with the result that they demand closed windows, weather strips on the doors, and furnaces at full blast. They would enjoy greater comfort and better health by lowering the temperature of the house and increasing the relative humidity of the atmosphere.

On the other hand many factories and workshops have high temperatures and high relative humidities, for example, laundries, etc. Under such conditions health and comfort are affected differently. People are much less efficient in a warm, moist atmosphere. The high degree of saturation in the air retards the rate of skin evaporation and the body temperature rises. Unless it is relieved, "heat prostration" occurs. The injurious effects of summer heat are almost always the result of combined heat and high humidity.

Poorly ventilated and crowded rooms produce conditions of high temperature combined with high relative humidity. The immediate ill effects produced in such rooms, like drowsiness and faintness, are mainly due to the heat plus the moisture.

**Forms of Atmospheric Moisture**

*The formation of dew, hoar frost, mist, rain, hail, snow*—All these phenomena result from the cooling of the atmosphere causing condensation of its water vapour. The particular manner of cooling and the temperature at the place of cooling determine which form shall appear. Air may be naturally cooled in the following ways.

1. By contact with cold surfaces, such as the earth's surface, leaves or stones.
2. By the mixing of masses of air of different temperatures.
3. By the expansion of a rising mass of air.
4. By the sudden expansion of air following lightning discharges during a thunder storm.

**Formation of Dew**

Dew is always formed by the condensation of water vapour, but it is not always produced entirely from the water vapour of the atmosphere. In considering the formation of dew we must first of all understand the meaning of the term *dew-point*.

The *dew-point* is the temperature at which the water vapour in the air begins to condense. This is not a fixed temperature but one which is very variable indeed. For dew to form, then, we must have certain conditions. Everyone knows that more dew is deposited during some nights than on others, and also that certain objects may be covered with dew drops while others remain nearly dry. How can this be explained? Clearly there are favourable and unfavourable conditions for the formation of dew.

If we compare the general state of the weather on several different nights, we shall see that dew is usually formed during those nights when the sky is clear. This is because clouds act like a blanket over the earth below them, preventing it from losing heat by radiation rapidly enough to let it cool below the dew-point. Again, we shall find that no dew is deposited on windy nights, even though the sky remains clear. The reason for this is that the water vapour is removed by rapid circulation before it can give up enough of its heat to condense. The fact that some objects are covered with dew drops while others are not at all, or very slightly, covered, is also due to the rate of cooling. Some objects like stones and pieces of metal heat up quickly and cool off just as rapidly; others, like wood, heat up very slowly and are slow to cool off.

Therefore stones, metal objects, and other similar good conductors of heat reach the dew-point temperature more quickly than do poorer conductors, like wooden objects. The result is that the good conductors of heat condense the most water.

In the case of dew drops on grass and leaves, the cause is somewhat different, for they themselves give out water through their stomata. If the air

temperature be low enough, this water vapour will be condensed to liquid drops as soon as it reaches the cold air surrounding the plants.

Dew is also formed by the condensation of the water vapour rising out of the ground. This fact can be easily verified for yourself by the following experiment.

**Experiment 41.**—*To show that a large part of the dew formed during the night has come from the vapour in the ground.*

*Procedure:* Take a pudding basin, or similar glass or earthenware vessel, and leave it upside down on the bare earth on a still clear night during the summer or early fall. At the same time leave another similar basin inverted on a dinner plate. In the morning you will find dew drops on the inside surface of the basin without the plate, but none inside the one you placed on the plate. What explanation can you offer?

**Hoar Frost**

In cold but dry weather, we often wake in the morning to find the inside of our bedroom windows frosted over with beautiful fern-like patterns. Out of doors we see the trees and other objects encrusted with a white, powdery deposit. This is *hoar frost.* Many people think it is frozen dew, but this is a mistaken idea. Hoar frost is formed by the direct freezing of water vapour, so that it is deposited from the air not as a liquid but as tiny ice crystals. It is a form of sublimation from water vapour into ice. Of course, real frozen dew may be and often is formed, but for this to occur, the dew-point must have been reached *before* the temperature had dropped to freezing.

**Mist and Fog**

Mist and fog are formed by the cooling of warmer, moist air when mixed with cooler air, and the resulting drops of water being held suspended in the air. Mists and fogs are exactly like clouds, but receive their special names from the fact that they form at either sea or ground

level. Fogs are simply mists dense enough to interfere with visibility. Mists are more common in valleys and other low-lying places and over bodies of water, than on high ground or in dry regions. They occur more often in valleys because, as air over the higher ground cools, it contracts and drains down any incline, however slight, into hollows of the ground. In these sheltered hollows the air may be still comparatively warm and above its dew-point, but the cold air draining into it cools it so much that its contained vapour condenses as a cloudy mist.

Sometimes this process goes on all night to such an extent that a whole valley may be filled with mist, so that on the following morning nothing can be seen of it from the heights above, where the air is clear.

**Clouds**

Clouds must not be thought of as masses of water vapour floating in the air. They are composed of tiny drops of water collected around very fine dust particles which are always present in the atmosphere. The formation of a cloud requires the cooling of the atmosphere below its dew-point and the presence of dust particles on which the condensed water may collect. The commonest cause of cloud formation is the cooling of ascending air. Clouds are also formed when a current of water-saturated air meets a colder and also water-saturated current of air.

Lastly they may be formed when masses of moist air are cooled by coming into contact with colder bodies, as, for example, clouds around a mountain top.

**Rain**

Rain is formed whenever the minute droplets of water forming clouds are condensed in sufficient quantities to unite together to form drops. When these drops of

water grow heavy enough to overcome the resistance of the air they fall to the ground as rain.

**Hail**

Hail consists of balls of ice. It is often called frozen rain, but although this is in a certain sense true enough, mere cold is not sufficient to cause hail. We know this because we never get hail in winter. Hail stones are always connected with hot weather. It is believed that hail is produced when the upward current of air in a cloud is very strong, and the resulting cooling by expansion is therefore sufficiently severe to cause freezing of the rain drops carried up by it. The violence of the convection current carries these frozen drops higher up into still colder parts of the air, where further ice layers are deposited on them. In this way the large hail stones are formed. That hail stones are built up by successive deposits of ice is shown by their banded structure. Since thunderstorms are formed by rapid uprushing currents of air, we see that it is natural to find them frequently accompanied by showers of hail.

**Snow**

Snow consists of minute hexagonal crystals of ice. It is formed by the cooling of the air when its dew-point is below freezing point. In this case the water vapour does not condense into a cloud of small droplets of water, but separates as a cloud of small crystals of ice. Sometimes these tiny ice crystals may be felt pricking the face as you walk or drive against a wind on a very cold winter day. Now, should these tiny ice crystals be separating out of the atmosphere in sufficient quantity, they deposit on those already formed and finally become heavy enough to sink to the ground as snowflakes.

That dust is always present in the air is a familiar

fact to most people. The enormous quantity and variety of the dust particles present in even the purest air is not often realized. These particles may be classified into two great groups, namely, the organic, or living, dust, and the inorganic, or lifeless, dust.

**The Dust of the Atmosphere**

*Organic dust* consists of the tiny spores of certain plant growths and of bacteria. The mould which appears on bread and fruit is caused by the spores of tiny plants falling upon the bread, and then germinating when the conditions of warmth and moisture are right. The mildew which appears on damp clothes is a plant growth which commences in a similar manner. The souring of milk and the tainting of meat are due to bacteria which are always present in the air. The fermentation of sugary liquids is caused by the presence of very simple plants called yeasts, whose spores are floating in our atmosphere in countless quantities. As soon as they settle on a suitable substance they spring into activity and multiply at an enormous speed. These living dusts are so plentiful in even the cleanest atmosphere, that it is impossible to expose any article for even the smallest space of time without some of them settling on it. This results in the spoiling of enormous quantities of food. If food is to be kept for any length of time we are compelled to do one of two things.

1. Kill all the bacteria upon it and then seal it up in such a manner that the living dust cannot get at it.
2. Lower the temperature conditions so that there is not sufficient heat to allow the germination of the spores or the multiplication of the bacteria or yeasts.

These objects are attained in several ways:

1. By immersing the food in liquids which will not spoil the food, but will kill the germs, e.g., pickles.

2. By drying out the moisture in the food so that the spores cannot germinate, e.g., dried fruits and dried beef.

3. By smoking, e.g., smoked beef and fish.

4. By sterilizing the food and sealing it in sterile air-tight containers, e.g., canned fish, fruit and vegetables.

5. By refrigerating, e.g., chilled beef and mutton.

Some of the bacteria floating around in the air find it necessary to enter the bodies of some plant or animal in order to complete their life history. Most of these kinds of bacteria are deadly enemies of the human race, because they produce many serious infections and contagious diseases, such as influenza, diphtheria, smallpox and typhoid fever.

Those which enter plant bodies cause fearful destruction of crops and forests.

Ergot on rye, smut on corn, and rust on wheat are examples of crop-destroying germs. The white pine blister rust is causing great destruction of the valuable white pine trees in our Eastern forests. It has destroyed practically all the white pines in Europe.

*Inorganic dust,* or lifeless particles in the air, consists of sand, soot, wool, hair, cotton, metal, and countless other substances. The size of the particles varies from about that of a pin's head down to particles so small as to be invisible even under a powerful microscope. On account of the smoke and manufacturing wastes as well as the traffic, the air over cities always contains more dust than country air. We have seen that dust is necessary for the formation of cloud and fog. This greater quantity of dust in the air of cities is held to account for the fact that fog is more prevalent in manufacturing cities than in the country.

*Sources of the inorganic dust in the air—*

1. From the burning of fuel.

2. From the wind action on the earth's surface.

3. From the effects of traffic wearing away the road surfaces.

4. From many manufacturing processes.

5. From volcanic eruptions.

6. From meteors.

*Effects of dust*—

1. It causes the formation of clouds by providing little centres on which the water vapour can condense.

2. It causes the haze so often observed in dry weather.

3. Dust particles cause the blue colour of the clear sky.

4. The gorgeous colours often seen in the sky at sunrise and sunset are sometimes due to light effects or dust particles.

## QUESTIONS

1. How does water vapour enter the atmosphere?
2. What is sublimation?
3. Name some of the conditions which affect the rate of evaporation.
4. Distinguish between absolute and relative humidity.
5. What do you understand by the term "saturated air"?
6. What is the name of the instrument used to determine the relative humidity of the atmosphere?
7. If the dry bulb thermometer of a hygrometer registers 68 degrees F., and the wet one registers 56 degrees F. at the same time, what is the relative humidity of the atmosphere? (Consult the table on page 168).
8. What is the effect of humidity on health?
9. How is dew formed?
10. Of what are clouds composed? How are they formed?
11. What causes rain to fall?
12. Account for the formation of hail in the summer time.
13. Write an explanation of a fog in winter.
14. Why do wet clothes dry more quickly in a breeze?
15. Explain how clothes dry if hung out of doors when the temperature is below zero.
16. Account for the cooling effect noticed when perspiration is evaporated from the face by fanning.
17. What is the difference between organic and inorganic dust?
18. How may we protect food from bacteria?

# PART THREE

# WATER

## CHAPTER XIII

## IMPORTANCE, FORMS, AND PROPERTIES OF WATER

**Importance of Water**

Water is one of the most abundant and valuable substances found on the earth. It is present in the atmosphere, on the surface of the earth, and in all rocks and soil. Water also constitutes the greater part of the bodies of all living things. It is estimated that about two-thirds of the human body consists of water and that plants contain from 50 to 90 per cent. of water in their tissues. In addition, water is absolutely essential to the very existence of every form of life.

The presence or availability of a water supply is always the deciding factor in choosing a place for human settlement. Not only does man require water for drinking and bathing, but without it he cannot raise crops or rear the animals from which he obtains the raw material for his food and clothing.

As the degree of civilization of a community increases, its uses of water grow more and more varied. In the form of steam, it is used to generate energy to run our great factories, and to drive our locomotives and ships.

In the liquid form it is used on a gigantic scale for the production of electricity, which is used to light our houses, drive vehicles and operate machinery.

Water is the principal agent in keeping our cities healthy, for running water is the chief agent in sewage disposal. In the form of ice, it is used for cooling and

refrigerating purposes, and also for controlling many industrial operations. Water is of importance in transportation. By far the greater portion of the commerce of the world is carried on water. To-day the importance of cheap transportation is such that all enlightened nations are taking fresh interest in canal and river transport. Water is the most important soil-making agent in nature. In various ways it is always wearing away the rocks in high places and carrying the product away to the low places. Tearing down in one place and building up in another, it is always restoring the fertility of the soil by fresh additions. In the process of soil-making, water, assisted by air, is one of the great agents in the production of scenery. The awe-inspiring precipices and canyons of the mountains, the delightful smiling valleys and the fruitful plains, the cool refreshing beauty of the lakes, all owe their particular appeal to the work and the presence of water on the earth.

**Forms of Water**

Material substances are capable of existing in three states or forms, namely, as solids, liquids, or gases. We are not aware that there is any other possible state or form of matter. Some substances are only known in one of these forms, for example, coal. Others are quite well known in two forms, for example, lard, iron. Others again are seen in all three stages, as for instance the wax of a candle, which we have already seen can be a solid, a liquid, and a gas.

Now any substance which is not changed into new substances by heating can be made to change from the solid into the liquid, and then into the gaseous form, by increasing the temperature. When the temperature is lowered the substance will revert from gas to liquid, and from liquid to solid. Such changes of form,

produced by applying heat to, or subtracting it from, a substance, are called *changes of state.*

Water is a substance which behaves in this manner. In consequence it occurs in nature as a solid, a liquid, and a gas, the particular form or state at any time

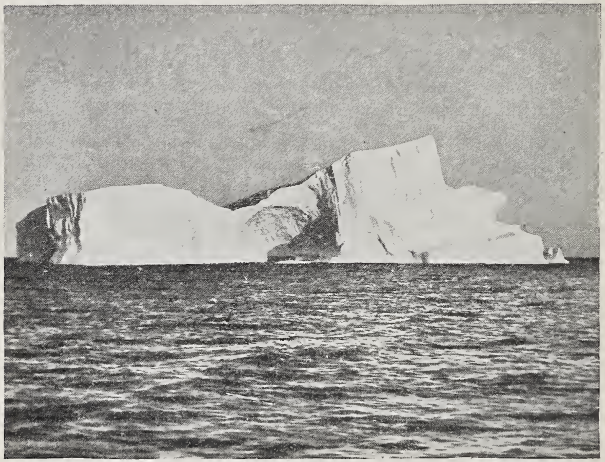

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**Fig. 64.—A Floating Iceberg**
The bulk of floating ice below the surface is about eight times as great as that above the surface of the water.

being determined by the temperature. When its temperature is below 0° Centrigrade water is a solid; when above 100° Centigrade it is a gas. At all temperatures between these points water is ordinarily a liquid. There are several varieties of each of these forms of water; e.g., ice and snow are varieties of the solid state; rain, soil-water, and clouds, are varieties of the liquid state; steam and water vapour are varieties

of the gaseous state. It is very important to remember that all these forms and varieties are not different substances, but are one and the same substance, water. The difference between them depends upon several things, the chief of which are *temperature, mode of formation* and *degree of purity.*

**Properties of Water**

*Weight*—Pure water in the liquid state weighs 1 gram per cubic centimetre when at a temperature of 4° C. Should water be cooled below, or heated above this temperature, it expands. This means that water is densest, or occupies the smallest space, when its temperature is 4° C.

This property of water is made use of to obtain the standards of volume and weight. The metric standard of volume is the *litre,* which is defined as being the space occupied by 1000 cubic centimetres of pure water when at its maximum density, that is, at 4° C.

The metric standard of mass is the International Standard Kilogram, which is equal to the weight of 1000 cubic centimetres of pure water at 0° C.

An Imperial Gallon is legally defined by the Canadian Parliament to be the space occupied by 10 pounds of pure water at a temperature of 62° F.

For practical purposes the weight of a cubic foot of water at 62° F. is taken as 62½ pounds.

**Density**

The density of a substance is the weight of a unit volume of that substance. Now because two countries may have different systems of weights and measures, it is evident that the people of these countries will represent the density of the same substance by different numbers. For example, in France the density, that is the weight of a unit volume of water is the weight of 1 c.c. of that substance, viz., 1 gram. In Canada,

however, it will be $62\frac{1}{2}$ pounds, since this is the weight of 1 cu. ft. of water.

This lack of uniformity in the sizes of the unit introduces a real difficulty when the people of different countries wish to compare the densities of things. To get round this difficulty, it has been agreed to compare the densities of all substances with the density of water. This practice is based upon the following principle. If a certain volume of mercury be weighed it will be found 13.6 times heavier than the same volume of water. Now it must be clear that it does not matter in what country this measurement is made, nor in what units its actual weight is expressed; it will always bear this weight relationship to water. Similarly a number may be obtained for any other substance, by comparing its weight with the weight of an equal volume of water.

The number so obtained for each substance is called its *specific gravity.* Note particularly that specific gravity is simply a number expressing a ratio; it has no unit name like pound or gram.

**Specific Gravity**

Since water is the standard substance used for comparison with other substances to obtain their relative densities, or specific gravity numbers, its specific gravity is always 1, no matter what system of weights and measures is used to make the comparison. There are a great number of specially designed instruments to enable the specific gravity of a substance to be simply and quickly found, for its determination is of the greatest practical importance. Knowing the specific gravity of any substance, the engineer can calculate from his drawings the weight of the whole, or any particular part, of a structure or machine he may be designing. The mining engineer is able, by determin-

ing the specific gravity of an ore, to estimate from his plans the probable yield of metal from a mine, and so to advise his clients as to the possibility of profit in their venture. The naval architect, by knowing specific gravities, can design vessels to carry any desired load with safety. He can also be sure that the ship will not ride so deep in the water as to be unable to enter the ports to which it is sent.

Specific gravity determinations also inform us about the condition of the storage batteries on our automobiles, and control the freezing point of anti-freeze solutions used in the cooling systems of automobiles. They are used by municipalities to maintain the quality of milk sold in their districts at a proper standard, and by physicians in the diagnosis of disease. These are but a few of the applications of specific gravity determinations, but they indicate their great importance.

*Pressure*—Because it has weight, water exerts pressure on any surface against which it rests. Water being a liquid, its particles are always trying to reach the lowest possible point. This causes its pressure to be exerted in every direction. Solids on the other hand only exert pressure in one direction, that is, vertically downwards. This is because the particles of a solid have no tendency to slip down to the lowest possible point. We have already learned that water weighs 62½ pounds per cubic foot. The pressure on a square foot of surface with a foot of water over it must therefore be 62½ pounds. If the same surface has two feet of water above it, the pressure upon it must necessarily be twice 62½ pounds, or 125 pounds. To find the water pressure in pounds per square foot on a surface under water, it is necessary to know the height of

the water above it in feet, and to multiply this figure by $62\frac{1}{2}$.

*Example*—What is the pressure in pounds per square foot exerted by a 12 foot depth of water on the bottom of a tank?

*Solution*—Pressure of water equals height of water in feet, multiplied by $62\frac{1}{2}$. Pressure equals $12 \times 62\frac{1}{2} = 750$ pounds per sq. foot. From this it is obvious that the amount of pressure exerted by a body of water is *proportional to the depth of the water.*

**Experiment 42.**—*To verify the principle that the pressure exerted by a body of water is proportional to the depth of the water.*

*Procedure:* Secure a tall tin can and with a nail punch three holes in the side, one about an inch from the top, another half way down and the third about half an inch from the bottom.

Plug up the holes with matches. Fill the can to the top with water. Remove the top plug and note the *energy* of the jet of water issuing from the hole. Replace the plug and fill the can again. Remove the second plug. Note the *energy* of the water flowing out of the hole. Replace this plug, fill the can once more and this time remove the bottom plug. Again note the *energy* of flow. Let the jet continue flowing and note how it behaves as the height of water in the can is lowered. The *energy* of flow may be considered as a measure of the pressure at the jet. What is, in your opinion, the cause of the difference in pressure at each jet?

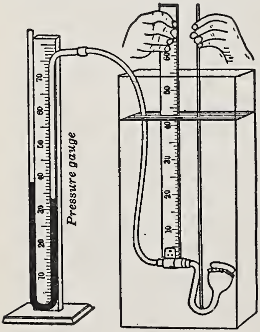


Fig. 65. — Gauge Shows Pressure in a Liquid is Equal in all Directions

In our study of air pressure we saw that air exerts pressure equally in all directions. Is this true of water?

**Experiment 43.**—*To find out if water exerts the same pressure in all directions at any given point.*

*Required:* A tall and wide glass jar nearly filled with water. A pressure gauge constructed as follows:

Cut off the top of a thistle tube so that its stem shall be about

1½ inches long. Connect this to a U-shaped glass tube having one leg of the U bent at right angles as shown in Fig. 65. Stretch a thin piece of rubber tubing over the mouth of the thistle tube and tie it firmly in place. Put some coloured liquid (ink) in the U-tube and shake until its level in each branch is the same. This is a simple form of pressure gauge. Its action can be seen by pressing lightly with the finger on the rubber membrane. The pressure transmitted to the air enclosed between the membrane and the coloured fluid in the U-tube is shown by the difference in levels of the liquid in the branches of the U.

*Procedure:* Carefuly lower the thistle tube into the jar of water, and as it is pushed deeper into the water notice the difference between the levels of the liquid in the branches of the U-tube. Does your observation confirm the previous experiment? Now stick two pieces of paper on the side of the jar each at a different distance from the surface of the water. Hold the thistle tube with the membrane up at the level of the first one, and note the level of the liquid in the U-tube. Very carefully turn the thistle tube in every direction in such a manner that the centre of the membrane is always at the same level as the paper on the side of the jar. Do the levels of the liquid in the U-tube alter with the change in direction of the membrane? Now repeat these operations at the level of the lower piece of paper. Is the difference in the U-tube level altered? Does it change as you turn the membrane in all directions?

*Conclusion:* If you have performed the experiment carefully you will find that the pressure downward, upward, and sideways is the same at the same depth.

It is now necessary to consider another aspect of water pressure. Suppose we have three vessels, the

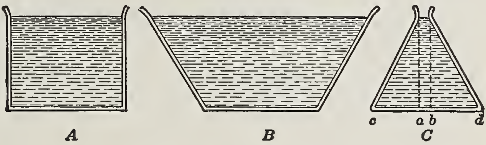



**Fig. 66.—Vessels with Variously Shaped Sides**
*A*, vertical; *B*, flaring; *C*, conical.

bottoms of which are of equal area, but whose shape and volume are not alike, for example, such vessels as are shown in Fig. 66. These vessels have bases of the same size, and are all of the same height, but their

sides are not alike. It is quite obvious that, when filled, B contains the most water and C the least.

If we were to weigh them, B would weigh heaviest and C lightest. Would you expect the pressure on the bottoms to be the same, or different, in each case? It is of little use to *guess* at the answer. We must find out the truth by experimenting.

The experiment which we shall use was first performed by Pascal, the great French scientist who helped to find out how to measure air pressures, and first used the barometer to measure altitudes.

**Experiment 44.**—*To find if the shape of the vessel and the amount of water it contains determine the amount of pressure on the bottom of the vessel.*

*Required:* A Pascal's vase apparatus.

*Description:* The apparatus consists of a number of different shaped glass vessels mounted in metal bases so that the areas of their bases are all the same. These all fit into a common base. This base is fitted with a moveable bottom held in position by a lever and weight. A moveable pointer, supported by a rod, is used to mark the height of the water, which must be put into the vessel so as just to open the moveable base.

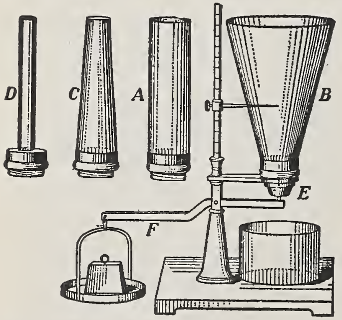



Fig. 67.—Pressure on Bottom is Independent of the Shape of the Vessel
(Pascal's vases).

*Procedure:* Attach the cylindrical vase A to the common base and support the moveable bottom in position. Place any suitable weight on the pan, and gently pour water into the vessel until it just forces the bottom open, allowing some water to escape. Mark the height of the water required, by adjusting the pointer.

Now remove this vessel and in succession substitute each of the other vessels, noting the height of the water required just to open the bottom in each case.

*Observation:* It will be seen that the same height of water is required for each vessel.

*Conclusion:* This experiment clearly shows that the pressure on the bottom of a container is independent of the volume of water in the vessel, and of the shape of the vessel, but is determined entirely by the height of the liquid above the base.

From the foregoing experiments on water pressure we have learned:

1. That water exerts pressure in every direction.
2. That water pressure is equal in all directions at the same depth.
3. That water pressure increases with the depth of the water.
4. That the pressure exerted by water does not depend upon the weight or volume of water present, but only upon its depth.

**Laws of Liquid Pressure**

These are very important laws and help to explain many rather puzzling effects of water pressure. They are known as the *Laws of Liquid Pressure,* since all liquids behave in the same manner. It is because of these laws that we are able to retain immense bodies of water behind the apparently slight walls of a reservoir. The thickness of a reservoir wall is not determined by the volume of water it is holding back, but by the depth of the water and the length of the wall. Also, because the pressure of the water is greatest at the bottom, such walls are built thicker at the base than at the top.

The use of a water tower to produce the desired pressure in the water mains of a town or city water system depends upon the action of these laws. The small body of water in the tower produces exactly the same amount of pressure as would be given by the waters of a great lake at the same height as the tower, because the pressure exerted depends

only on the height or depth of the water, and not at all on the volume of water present.

Another very important result of these laws is expressed by the phrase, *water seeks its own level.* We are all familiar with this statement and we see it in action in the kitchen every day. The water level is the same in the kettle and its spout. If the pressure exerted by water were due to the quantity of water present, then the greater quantity of water in the body of the kettle would force the smaller amount of water out of the spout. That is, it would be impossible to keep the kettle full of water. But we can keep water in the kettle, because the pressure exerted by the water in the spout is equal to that exerted by the much larger volume of water in the body of the kettle. This equality is due to the fact that the pressure in a liquid depends upon the depth below the free surface. That "water seeks its own level" may be demonstrated experimentally by the aid of the apparatus shown in Fig. 69. This apparatus consists of a number of tubes of different shapes and volumes. They are connected together by the tank at their bases. Fill the tank with water so that the surface of the water just

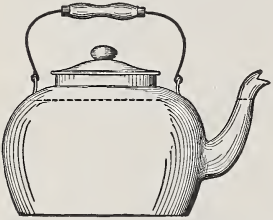


**Fig. 68.—Water Seeks its Own Level in a Tea-kettle**

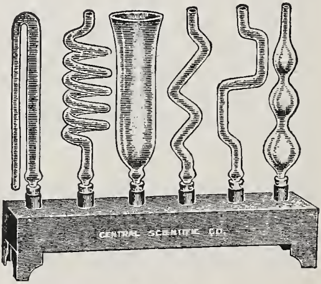


**Fig. 69**

shows in the small bulb at the base of each tube. Now fill the widest tube with water and watch what happens. The water will flow out of this tube and rise in all the other tubes until the water level is the same height in each. Successive fillings of the wide tube, or any other for that matter, will always result in the water coming to rest at the same level in each vessel, no matter what its size or shape.

**Buoyancy**

Many familiar experiences tell us that bodies seem to lose weight when in water; for example, those of you who go swimming know that, while in the water, you can walk on your toes quite easily, but that it is very tiring, not to say painful, to do so out of the water. Also anyone who has drawn water from a well knows about the sudden increase in weight as the bucket leaves the water. Again, it is easier to move objects when they are in water than out of it; for example, it may take several persons to get a boat into the water, but once there it may be quite easily moved about by one person. If we wonder about these things, and ask for an explanation, we are told that "the buoyant force of the water supports them". The buoyant force of a liquid, then, may be said to be the lifting effect of that fluid on any object immersed in it. It is this lifting effect which causes objects in the fluid to seem to weigh less than when out of it. The question now arises, how much lighter is an object under water than when it is out of water, or, in other words, what is the amount of the buoyant force exerted by the water upon the object?

**Experiment 45.**—*To determine the buoyant force that water exerts upon a body immersed in it.*

*Apparatus Required:* A balance and weights, a beaker and water, some thread, a wooden bridge capable of straddling the

balance pan without interfering with the motion of the balance, a bucket and cylinder apparatus. See Fig. 70.

*Procedure:* Examine the bucket and cylinder apparatus. It consists of a solid cylinder of brass, A, which has been carefully adjusted so that it just fits the hollow bucket, B. Evidently, then, the space inside the bucket exactly equals the volume of the cylinder. The hooks and bail are for suspension.

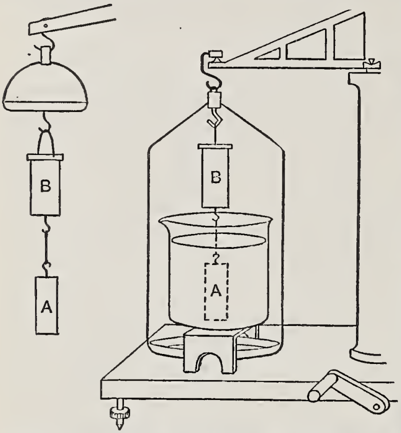


**Fig. 70.—Buoyant Effect of Liquids is Equal to Weight of Liquid Displaced**

Place the wooden bridge over the left-hand pan of the balance and place the empty beaker upon it. Take the cylinder out of the bucket and hang it on the hook at the bottom of the bucket. Suspend the apparatus from the hook on the left-hand arm of the balance. (Do not remove the pan in order to do this.)

Arrange the suspension so that the cylinder will be within the beaker throughout the experiment.

Now weigh the apparatus. This will be its weight in air. Next carefully pour water into the beaker so that the cylinder is completely surrounded with water. Take great care that the water cannot touch the bottom of the bucket when the balance is swinging.

It will be observed that the balance is destroyed. If now water be carefully poured into the empty bucket equilibrium will be restored when the bucket is just filled with water.

If we substitute another liquid for the water, say coal oil or wood alcohol, or even salt water, and repeat the experiment, we shall find that the results are exactly the same. Always the equilibrium is restored by filling the empty cup with the same liquid that surrounds the solid cylinder.

*Conclusion:* From these experiments we conclude that the buoyant force exerted by any liquid on any body immersed in it is exactly equal to the weight of the liquid displaced by the object. Sometimes this important principle is stated in a somewhat different manner, but a little thought will show that both statements mean the same thing.

A body, when weighed in a fluid, loses in apparent weight an amount equal to the weight of the fluid which it displaces. These laws of buoyancy are called the *Principle of Archimedes*, after the great Greek scientist who was the first man to discover and understand the principle of buoyancy. He lived at Syracuse in Sicily, where he was killed by a Roman soldier in the year 212 B.C.

**Explanation of the Principle of Archimedes**

Suppose we have a solid cube measuring one foot each way. This is a body having six faces, each one square foot in area. Now let us imagine this cube held down in a tank of water so that its upper surface is three feet below the surface of the water.

We have already learned that the pressure on any surface within a liquid is governed by the depth of that surface below the top of the water.

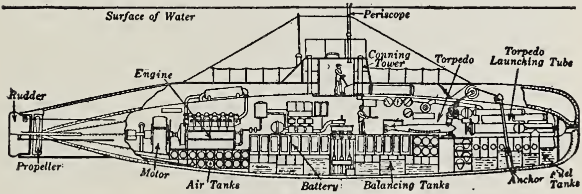



**Fig. 71.—The Submarine Floats or is Submerged by Varying its Density.**

In the case of our cube, therefore, the pressure on each surface will be:

Top surface = 3 × 62½ lbs. = 187½ pounds downward.

Bottom surface = 4 × 62½ lbs. = 250 pounds upward.

Each side = $3\frac{1}{2} \times 62\frac{1}{2} = 218\frac{3}{4}$ pounds exerted horizontally either right or left.

Now the sideways pressure being the same on either side, they balance each other so that there is no tendency for the object to be pushed either to the right or left. But the upward pressure is greater than the downward pressure by $62\frac{1}{2}$ pounds or the weight of one cubic foot of water; that is, by the weight of the volume of water displaced by the cube.

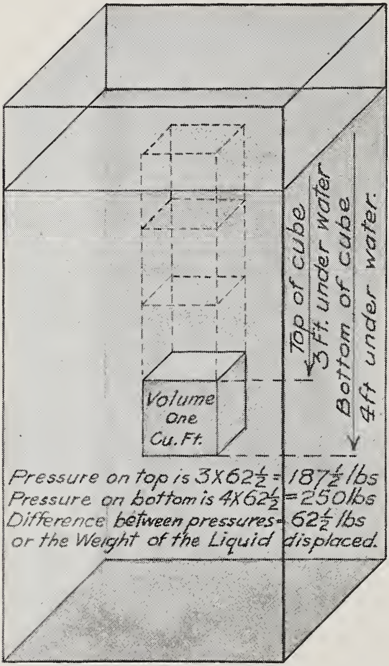



**Fig. 71a.—Diagram to Illustrate the "Explanation of Archimedes' Principle" on page 191**

It is this displaced liquid, always trying to slip back into its place, that produces the lifting or buoyant force on any object immersed in a liquid.

The principle of Archimedes explains why some bodies sink while others float when immersed in a liquid. If the body weighs

more than the liquid which it displaces then it will sink. This is because the force exerted by gravity upon it is greater than the buoyant force exerted by the liquid. Motion always takes place in the direction of the line of action of the greater force acting upon a body. Therefore the body moves downward; that is, it sinks. Conversely, if the body weighs less than the liquid it displaces, then the upward force exerted by the water is greater than that exerted by the downward pull of gravity, and the body rises out of the water until these forces are equal; that is to say until the amount of water displaced just equals the weight of the body. This is the *Law of Floating Bodies.* A floating body displaces its own weight of the liquid in which it is floating.

**Why Things Float**

**Experiment 46.**—*To prove the law of floating bodies.*

*Apparatus Required:* A rod of wood 1 centimetre square and 30 centimetres long, weighted at one end with lead so that it will float vertically when placed in water. This rod should be marked on one face with a centimetre scale, and dipped into hot parawax to make it waterproof. A tall glass jar filled with water. Balance and weights.

*Procedure:* Weigh the rod on the balance and note its weight in grams. Put the rod in the water and note how far it sinks in the water, in centimetres. Since 1 gm. is the weight of 1 c.c. of water, the number of cubic centimetres immersed in the water will be the same as the weight of the rod in grams.

*Conclusion:* A body when floating displaces its own weight of the liquid in which it floats. This is the Law of Flotation.

**Transmission of Pressure by Liquids**

Water, or any other liquid, can be used to carry pressure from one place to another. So also can solids or gases. Now liquids or gases behave very differently from solids in transmitting pressures. A solid can only transmit pressure in one direction, the same direction in which the original pressure is applied. Liquids and gases on the other hand transmit the pressure in every direction through-

out their mass. This is a very important property of fluids, and one which is very useful to man.

Experiment 47.—*To find out in which direction a liquid transmits pressure.*

*Apparatus:* A glass pressure syringe with perforated bulb.

*Procedure:* Fill the syringe with water and then push in the piston. The water is expelled through every perforation in the bulb, not merely through those which lie in the direction in which the force is being applied. It will also be seen that the streams of water are all leaving the holes at right angles to the surface of the bulb.

*Conclusion:* From these observations we conclude that pressure exerted anywhere on an enclosed liquid is transmitted in all directions through the liquid, and presses on all the enclosing surfaces at right angles to them.

*Note:* If a pressure syringe is not available a rubber ball which has been perforated in several places may be substituted. The same results can be obtained but the directions of the issuing streams of water may not be truly at right angles to the ball's surface. This is due to the difficulty of perforating such an object satisfactorily.

If you are thinking about what is going on, you will naturally want to know how much pressure is exerted at each of these little holes in the bulb. If you have ten holes, is one-tenth of the pressure exerted at each hole, or do some holes receive more pressure than others? Is the total of the pressure at all the holes equal to, less than, or greater than the pressure applied in squeezing the bulb?

**Pascal's Experiments**

The first man to investigate and explain the transmission of pressure through liquids was Pascal, of whom you have already heard. These questions also occurred to him, and he set himself the task of answering them. To do this, Pascal performed many experiments, one of which we will consider here. Observe Fig. 72. Here we have a tank in which there are three openings, two on the top and one at the side. Each of these has the same area, and is fitted with a piston. If the box be completely filled with water

and a weight be placed on the piston at A, it will be found that exactly the same weight must be put upon the piston at B to hold it in place. In the case of the piston at C it will require a force equal to the weight on A plus the pressure on C due to its depth. This shows that any external force applied to an area of any confined liquid is transmitted without loss to every similar area of the inside of the containing vessel.

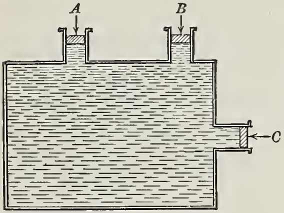



**Fig. 72.—Box Filled with Water and Fitted with Three Equal Pistons**

Now study Fig. 73. Here we have a cylinder of one square inch in area connected by a pipe with another one which has an area of 100 sq. inches. Each cylinder is fitted with a piston. If a pound weight be placed on the one inch piston, the piston in the other cylinder will rise.

What weight must be placed upon this larger piston to hold it down? Think of the last conclusion reached: any external force applied to an area of any confined fluid is transmitted without loss to every similar area of the inside of the containing vessel. From this we deduce that one pound pressure on an area of one square inch will be transmitted without loss to each square inch of the piston. That is to say that 100

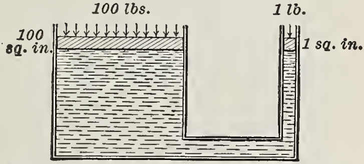



**Fig. 73.—Forces Exerted on Pistons Vary as their Areas**

pounds would have to be placed upon this large piston to keep it in place. This shows that liquids may be used to multiply pressures, and that the relation between the pressure exerted and the new pressure produced will be in direct proportion to the areas of the surfaces concerned.

These very important facts are summed up in a well-known scientific law called *Pascal's Principle,* which states that *"pressure exerted anywhere on an enclosed fluid is transmitted equally and without loss to all equal surfaces, and acts in a direction at right angles to them."*

As we shall see later, in our study of force pumps and hydraulic presses, great practical use is made of these laws governing the pressures of liquids.

**Solvent Power**

Solvent power is a property possessed to a greater or lesser degree by all liquids. We are all familiar with the fact that salt or sugar, when put into water, disappears from sight. We say they have dissolved and that a solution has been formed. This action is not confined to solids, but may take place with other liquids, and also with gases.

Solution as ordinarily understood is the act of evenly distributing a substance throughout the mass of a liquid so that it is lost sight of as a separate body.

The substance dissolved is called the *solute.*

The liquid used is termed the *solvent.*

The resulting liquid is known as the *solution.*

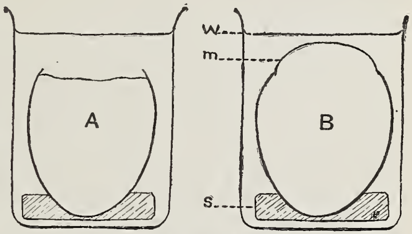
Water is the greatest of all solvents. It dissolves so many solids, liquids, and gases that it is called the "Universal Solvent".

Upon this great solvent power of water many of the major processes of nature depend. Animal life in the water could not exist but for the power of water to

dissolve oxygen. Plants would not be able to obtain some of their most valuable food stuffs unless water were able to dissolve them. Animals could not assimilate their food if the watery part of their blood were unable to dissolve the digested food materials. All the mineral springs of our many health resorts are partly the result of the great solvent power of water. The process of soil-making is largely dependent on the power of water to dissolve minerals out of the rocks. But this high solvent power is often a disadvantage, because it makes more difficult the already sufficiently difficult problem of maintaining the purity of the water supply of a community.

**Osmosis**

Osmosis is a property possessed both by liquids and gases. It is without doubt one of the most important of natural forces. Upon it depend all forms of animal and plant life in the world. Not one single plant or animal is capable of either respiring or assimilating its food without the assistance of osmosis. Most of us are familiar with the fact that if a dried fruit with its skin unbroken be placed in water, it will swell up almost to the original size. This change is due to osmosis. The inside of the fruit contains sugar. When the fruit was




*From Gager's Fundamentals of Botany*

**Fig. 74.—Osmosis Through Egg Membrane**

A, at the beginning of the experiment; B, about one hour later; w, surface of water; m, egg membrane; s, support of egg. Explain the difference between A and B.

dried, the water inside the skin passed out and left the sugar behind. A membrane which will allow one substance to pass through it but retains another one is called a *semi-permeable membrane.* When we placed the dried fruit in the water the fruit gradually regained its original size because the water passed easily through the skin. After passing through, it dissolved the sugar, thus forming a liquid inside the skin heavier or denser than the water outside. Now this sugar solution is not able to pass out through the skin as fast as the water outside enters. This results in a pressure being exerted on the inside of the skin, which causes the fruit to swell.

Osmosis may therefore be defined as the exchange which takes place between two fluids of different densities when separated by a moist semi-permeable membrane. The rate of exchange is always faster from the weaker solution towards the denser one. This statement is called *The Law of Osmosis.*

**Experiment 48.**—*To demonstrate osmosis and to verify the law of osmosis.*

1. To show clearly that fluids can be exchanged through a moist semi-permeable membrane.
2. To show that the rate of exchange is greater from the weaker to the stronger solution than vice versa.

*Required:* Two vessels, one containing tap water and the other a strong solution of salt, a potato.

*Procedure:* From the potato cut two oblong, rather thick slices, both about the same size. Note their colour and crispness. Put one slice in the vessel containing tap water and the other in the vessel containing the strong salt solution. Leave undisturbed for several hours.

At the end of this time, remove the slices and note the colour and crispness of them, and also inspect the liquid in the vessels for sediment. You should find the slice from the tap water has become crisper, and that its colour is unchanged.

The slice which was in the salt water has, however, changed colour and is now very flabby.

Also at the bottom of the vessel containing salt solution you will notice a whitish sediment. This sediment is largely starch.

Now reverse the experiment, putting the flabby slice from the salt solution into the fresh tap water and the slice which had been in the tap water into the salt solution.

After several hours examine the slices again. The flabby slice from the salt solution has regained much of its crispness, although it is still discoloured, while the crisp slice has turned flabby and become discoloured from its immersion in the salt water.

*Conclusion:* The increase in crispness must be due to something entering into the cells of the potato. The decrease in crispness must be caused by something leaving the potato cells. Therefore we conclude that since the crispness is increased whenever the potato is placed in tap water, the less dense fluid, water, flowed into the potato cells *faster than the denser cell sap could flow out.*

In the case of the slice immersed in the salt water, the starch solution must have flowed out of the potato cells toward the salt solution faster than the salt solution could enter the potato.

Now the salt solution is a denser solution than the solution within the cells. Therefore the exchange of solutions is in both cases more rapid from the weaker to the denser solution. That starch passed out of the potato cells when the denser solution was outside the potato, is shown by the sediment of starch in the salt solution.

The law is still further confirmed by reversing the slices and noting that the flabby slice taken from the salt solution regains its crispness when put into the water, and vice versa.

It is also evident that fluids can pass through semi-permeable membranes when they are moist.

**Surface Tension**

Surface tension is a property common to all liquids, by virtue of which the free surface of any liquid behaves as if it were a stretched elastic membrane. Many simple and easily performed experiments demonstrate the presence of this elastic "skin" at the surface of liquids.

**Experiment 49.**—*To show that the surface layer of a liquid will stretch before breaking.*

1. Take a small beaker or wine glass and fill it to the brim with water. Then carefully drop into it coins, or other bits of metal. The water slowly rises above the edge of the vessel and appears to be held by an elastic skin which clings to the rim of the vessel. As more objects are carefully slid into the water its surface becomes more and more convex until at last the skin breaks and the water runs over the edge.

2. Take a safety razor blade that is quite dry, and carefully lay it flat on the surface of the water in a wide vessel. It does not sink. Carefully examine the liquid around the blade and you will see that it is bent down by the weight of the blade. If your hand is very steady you can place quite a number of small flat objects on the floating blade and the surface of the water will bend further and further, until at last the weight breaks the "skin" and the objects rapidly sink to the bottom.

3. Take a pie plate and get it very hot, then drop a little cold water on it. The water runs about the surface of the plate in little drops without actually touching it, being supported by a layer of vapour from the water. This is often called the "Spheroidal State" of water, because the drops are round. Now this roundness is just what we should expect if the complete surface of each drop should behave as if it were an elastic skin. The elastic "skin" is always trying to become smaller and smaller and, because the drop is not touching anything, the shape must be that for which the least surface is possible. Now the solid which has the least surface for the greatest volume is a sphere. This is the reason why raindrops are round. It is also the reason for the perfect roundness of soap bubbles.

Surface tension finds many practical applications. If there were no such thing as surface tension, painting would be a messy and perhaps impossible operation, for it is this tendency of the surface of the liquid paint to keep as small as possible which holds the paint in the brush, thus enabling the painter to apply it where he will.

It is also made use of in waterproofing cloth without the use of oils or rubber. Cravenette cloth is an example. The fibres of this cloth have been treated with a preparation which prevents the water from adhering to them. The water therefore will not run in between the fibres, but assumes the spheroidal state and rolls off the garments, thus keeping the wearer dry. Surface tension is also practically applied in making lead shot, by dropping molten lead from various heights down a "shot tower". It is also of great practical importance in the process of dyeing.

**Capillarity**

Whenever the surface of a liquid is brought in contact with a solid, a change occurs in the level of the surface of the liquid. These changes may be easily demonstrated by the following experiments

**Experiment 50.**—*To demonstrate the change of level at the surface of a liquid when in contact with a solid.*

1. Take a set of capillary tubes. These are short lengths of glass tubing whose internal diameters are quite small, say

from 2 mm. and down. Support them in a shallow dish in a vertical position. Now place some coloured liquid in the dish so that all the lower ends of the tubes dip into the liquid. Then inspect the tubes. It will be seen that the liquid is at a different height in each. The finer the tube the higher the liquid has risen it. This change cf level is said to be due to *Capillary Action.*

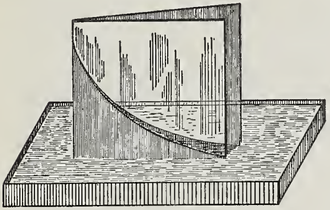


**Fig. 75**

2. If a set of tubes is not available, the experiment may be performed just as well in another way. See Fig. 75.

Take two squares or oblongs of window glass and place them face to face, with a strip of wood between to keep them slightly apart along one edge while they meet along the opposite edge. Tie them together so as to hold them in this position. Then stand the whole affair upright in a shallow dish containing coloured water. The water at once creeps up between the plates, standing highest where they meet.

3. Take two narrow test tubes and put some water into one and mercury into the other. Examine the surface of each and note its shape. The edge of the water is turned up while the edge of the mercury is turned down. These effects are also due to capillary action. But why should the edge of one liquid be pulled down and the other up? Pour the liquid out of the tubes. The one which contained the water is wet while that which held the mercury is dry. This answers the question. Capillary action may cause a rise or a fall in the level of the surface of a liquid where it is in contact with a solid. If the liquid does not wet the solid then the level of the surface of the liquid is depressed.

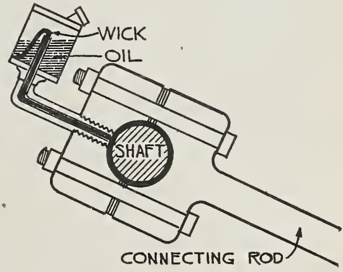



Fig. 76.—**Lubrication of Machinery by Capillary Action Along a Wick**

Capillarity then may be defined from the above experiments as being *the force which tends to alter the level of the*

*surface of a liquid when the liquid is brought into contact with a solid.*

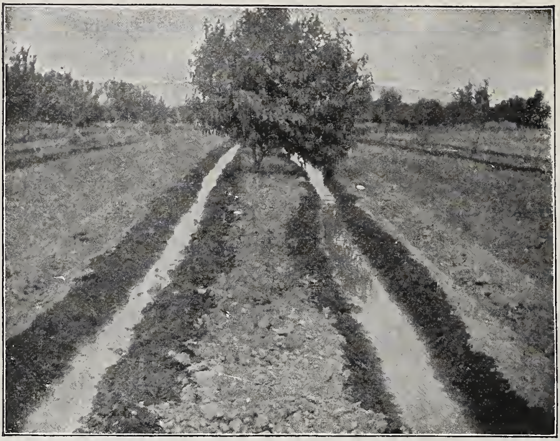


Fig. 77.—Capillary Spreading of Water through Soil from Water Furrows in Peach Orchard

Capillary action obeys two chief laws:

1. If the liquid wets the solid the liquid rises above its general level, but if it does not then it sinks below its general level.

2. If the solid contains spaces, e.g., a tube, a mass of soil, or the meshes of a piece of cloth, then the amount of rise or depression is inversely proportional to the areas of the spaces. That is to say, in tubes it is inversely proportional to the diameter of the tube.

Capillary action is of great natural and practical importance. We use it every day in absorbing liquids, e.g., drying our hands and faces after washing, wiping the dishes, and blotting ink. Lamps and candles are kept burning by the capillary rise of oil or melted

wax up the fibres of their wicks. Lubrication of machinery is often carried out by capillary action along a wick placed in a well or cup of oil. See Fig. 76. Capillarity assists very greatly in the circulation of the sap of plants. Water is lifted from the great store of underground water to the roots of the plants by the capillary rise through the particles of the soil.

## QUESTIONS

1. Summarize in a story the value of water in the life and activities of man.
2. Name 10 different and distinct uses of water.
3. In how many forms does water occur in nature? Name them.
4. Distinguish between density of a substance and its specific gravity.
5. If the specific gravity of a brick be 2.2, calculate the weight of the bricks in a wall 10 ft. high, 20 ft. long and 14 inches thick.
6. If oak has a specific gravity of 0.9, what will an oak chest 3 ft. x 18 inches x 18 inches inside measurement weigh when constructed of oak boards 1 inch thick?
7. How many pounds of gasoline (Sp. G. 0.66) are contained in a 10 gallon automobile tank?
8. Mention some uses of specific gravity determinations to (a) Garage men, (b) Municipal Officials, (c) Engineers.
9. Explain the uses of water depending upon the following characteristics, giving one clear example of each: (a) its weight, (b) its solvent power, (c) its incompressibility, (d) its capillary action, (e) its evaporation.
10. Describe an experiment to illustrate osmotic action. Give an example of osmotic action commonly used in the kitchen.
11. Why does a heavy stone seem lighter when it is submerged in water?
12. Why do some bodies float, and others sink in water?
13. What is (a) a solute, (b) a solvent, (c) a solution?
14. Name 4 common household operations which make use of capillary action.

## CHAPTER XIV

# MAN AND THE PROPERTIES OF WATER

Most of the properties of water studied in the last chapter are set to work for us in many ways.

This chapter will be devoted to a survey of some of the more important uses and effects of these properties of water.

In engineering practice the term water power is used to designate two things:

**Water Power**

1. The energy obtained from running or falling water and used for the production of industrial power.

2. The energy that is available in the waterfalls, rivers, and lakes of the world, but is not yet being used for the production of power.

The use of running or falling water as a source of power was undoubtedly one of man's earliest attempts to harness natural energy to do his work. Until the perfection of the steam engine it was the most important source of industrial power available to man.

For a while the advantages of the steam engine led to the abandonment of water power as a large-scale source of power production. This was largely because the early devices for using water power compelled the location of the factories on the banks of streams. The steam engine on the other hand allowed the factories to be erected at any place to which fuel might be transported. At the present time we are witnessing a return to the use of running or falling water as a source of industrial power on the most gigantic scale. This

is due to the wonderful development in the production and transmission of electricity. To-day it is no longer necessary to locate the factories near the water-power site. On the contrary, power houses are

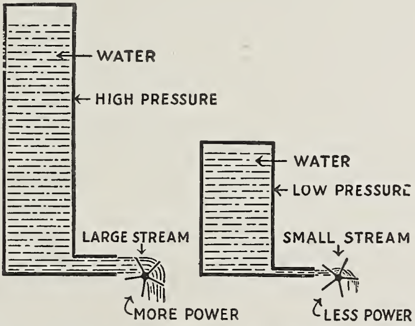



**Fig. 78.—A large stream of water at high pressure delivers more power than a small stream at low pressure**

often located at places quite difficult of access, while the factories using the power are placed in more favourable situations, quite long distances away from the power house. This separation is made possible, because man has discovered the means of taking the power yielded by running or falling water and transmitting it in the form of electricity hundreds of miles over hills and plains to the point where he can put it to useful service. This is one of the great victories of modern science and engineering.

**Water has no Power**

When we speak of water power we are apt to think of the water as actually furnishing the energy. This is not the correct view to take, as it is not water, but gravity, that really drives the machinery. The water is simply

the medium that gravity acts upon. The energy obtained from water power is the result of the water possessing weight and falling from a higher to a lower level. The vertical distance between these levels is called the *head* of water. The greater the head which can be obtained the greater the energy that can be produced.

Every stream of water is constantly flowing from a higher to a lower level, so that all streams have a "head". In many cases this "head" is so small that the water flows too slowly to produce much energy. In such cases the engineer often obtains a sufficient head by constructing a dam across the stream. Even where the stream flows fast enough to perform useful work, dams are usually constructed, not only because they increase the head but because they regulate the rate of flow. There are two distinct types of machines by which the energy of moving water is utilized, namely, water wheels and turbines.

These machines will be studied in Part 5 under the topic "Generation of Energy". Most of the water power in use to-day is obtained from waterfalls and rivers. There is available, however, the stupendous amount of energy produced daily by the rise and fall of the tides. For hundreds of years the utilization of this force, as a source of power, has been the dream of engineers and scientists. Several attempts have been made and are still being made to harness this mighty force. Should success crown the efforts to control this energy, Canada will be able to add an enormous total to her already magnificently great water power resources.

The development of water power resources should be of the greatest interest to Canadians. No other country in the world possesses such marvellous water power resources, that are so well placed with respect to the

world's great trade routes and nearness to great manufacturing centres. Canada's wonderful water powers, backed by her great natural resources of farm, forest, and mineral wealth, must inevitably result in a great industrial expansion which will make her one of the world's greatest manufacturing nations. Already this is foreshadowed by the rapid industrial expansion in Ontario and Quebec following the hydro-electric development in these provinces.

**Water Systems**

Cities and towns are provided with water systems so that an ample and continuous supply of good water shall be available for:

1. Drinking and other domestic purposes.
2. Industrial purposes.
3. Sanitation.
4. Fire protection.

The water is usually obtained from rivers, lakes and artesian wells. The problem of maintaining an ample

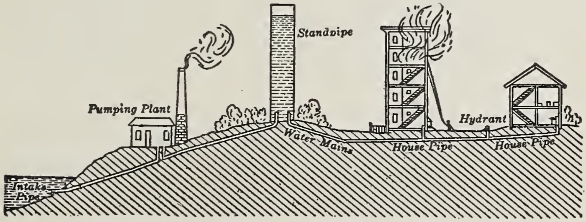



Fig. 79.—Cross Section of a Water System

supply of wholesome water for a large community is both difficult and expensive. It is one, however, that no community may shirk without lowering the standard of health or laying itself open to the scourge of epidemic diseases.

Not only must the water be secured, but it must be furnished at sufficient pressure to force it to the tops of the highest buildings of the town. Three systems of obtaining this required pressure are in use:

1. The simple gravity system.
2. The pumping system.
3. The combined gravity and pumping system.

The system chosen depends largely upon the location of the city and its natural environment. Cities located near mountains adopt the simple gravity system, because it enables them to dispense with an expensive pumping installation. In such systems a natural lake situated high in the mountains is chosen for the source. If this is not possible then a reservoir is formed by damming up the valley of a mountain stream. Large pipes or aqueducts lead the water by simple gravity flow from these reservoirs into mains and supply pipes to the city. The reservoir is usually many hundreds of feet higher than the highest building in such cities. Good fire protection is afforded by this type of water system, since water pressure at any point depends upon the height of the column of water above it.

**Simple Gravity System**

The placing of the reservoir so high above the town ensures a heavy water pressure at the nozzles of the fire hoses, usually sufficient to throw the stream of water much higher than the tallest building in the town.

Halifax, N.S., St. John, N.B., Quebec, P.Q., Banff, Alberta, and Vancouver, B.C., all use the simple gravity system for their water supply.

Some cities, notably those situated on the banks of rivers, or near lakes, make use of the pumping system. The water is pumped from the source of

supply and passed through filters and treatment tanks. The purified water is then pumped into the distributing mains and pressure maintained in them by pumps. This method is characteristic of towns situated in regions having little surface relief. Moncton, N.B., Montreal, Toronto, Ottawa, Winnipeg, Regina and Edmonton all use this system.

**The Pumping System**

*The combined gravity and pumping system*—In this system the water is pumped from rivers, lakes and wells into a stand pipe or elevated reservoir, and allowed to flow from the stand pipe or reservoir by gravity into the distribution mains. It is a system well suited to small towns located in flat country. It is interesting to note that the diameter of the stand pipe is of no importance in producing the pressure necessary to ensure the distribution of the water. Sometimes gravity pumping systems reverse this method. That is, the water flows from the source of gravity into a reservoir and the water is pumped into the mains from the reservoir, the pressure necessary to secure distribution being maintained by the pumps. Canadian towns and cities using the combination system are Glace Bay, N.S., Woodstock, N.B., Sherbrooke, P.Q., Port Arthur, Ont., Brandon, Man., Saskatoon, Sask., Lethbridge and Calgary, Alberta, Victoria, B.C.

**The Force Pump**

Force pumps are devices designed for use when it is found necessary to raise water to a considerable height, or to drive it with great force through a nozzle, as for example in a fire hose. They are also used when we wish to force water into a space against great pressure, as for example in forcing water into a high-pressure steam boiler. They, like lift pumps, use atmospheric

pressure to raise the water to the cylinder. They, however, differ from lift pumps in two important respects:

1. They have no valve in the piston.
2. They use the pressure of the piston to force the water to the required height, or to overcome some resistance to its flow.

Force pumps may be either single-acting or double-acting. That is, they may lift the water on the down-stroke of the piston only, or they may lift it on both the up- and the down-stroke.

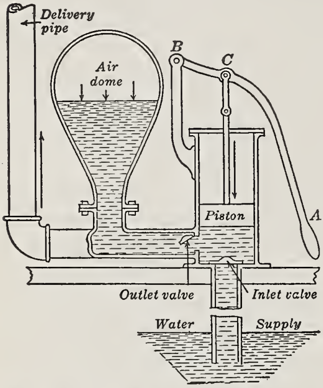



**Fig. 80.—A Force Pump with an Air Dome**

The single-acting variety delivers the water in a series of powerful spurts, while the double-acting pumps deliver a steady stream of water at a high pressure. The incompressibility of water and its property of transmitting pressures without loss in all directions render these pumps subject to severe jars every time the piston exerts pressure on the water. In order to lessen the severity of these jars, force pumps are fitted with shock-absorbing devices in the shape of an air dome attached to the delivery pipe. The air trapped in the dome is compressed by the pressure of the rising water. This causes it to act like a cushion or spring, thus relieving the pump of much of the shock. When the pressure of the water lessens because of its escape through the delivery pipe, the air expands again and

assists in maintaining the steadiness of the water pressure in the jet.

Consider Fig. 80, which shows the essential parts of a single-acting force pump. When the lever is raised the piston ascends. Atmospheric pressure on the surface of the water causes the water to open the valve and fill the cylinder. The downward pressure of the water in the delivery pipe keeps the valve at its lower end closed.

**How the Pump Acts**

On the downward stroke of the piston the pressure exerted by it on the water closes the valve. There being no valve in the piston, the water in the cylinder is forced through the valve of the delivery pipe and travels up the pipe, compressing the air in the dome. When the piston is raised again, the weight of the water closes the valve of the delivery pipe, and the compressed air in the dome expands, pushing the water out of the delivery pipe.

The height to which water can be raised by a force pump depends upon the pressure that can be exerted on the piston. This in turn is limited by the strength of the pump and its parts.

Double-acting force pumps have an extra set of valves, so that the piston is enabled to exert pressure on the water in the cylinder on both its up- and its down-strokes.

**The Hydraulic Press**

We have seen that, about the middle of the seventeenth century, Pascal showed it was possible to produce enormous pressures by completely enclosing a mass of water and exerting a small pressure on a fraction of its surface. Now it is often a long and difficult task to turn a small laboratory apparatus into a practical commercial machine. Many great and successful in-

ventors tried their hand at the job and were signally defeated. At last, in 1796, Joseph Bramah, an English engineer, and a young mechanic employed by him, named Henry Maudsley, solved the problem and invented a practical machine by which Pascal's principle could be put to work. We call this machine the Bramah, or Hydraulic press. It consists of a cast-iron cylinder having very strong, thick sides in which there is a cast-iron water-tight ram, P, moving in the collar of the cylinder. On the ram there is a cast-iron plate on which the substance to be pressed is placed. Four strong columns serve to support, and hold fixed, a second plate against which the substance to be pressed can be pushed. The cylinder is connected by a small pipe to a small force pump fitted above a tank, C, which in turn is connected to the water supply system by a pipe near the top of the tank. There are two valves, one in the cylinder of the press at "v", and the other in the force pump at "d". When the piston of the first pump "p" is raised by working the handle E, a vacuum is produced, and the water rises into the barrel of the pump through the valve "d". On the down-stroke of the piston the valve "d" closes, and the water is forced through the pipe.

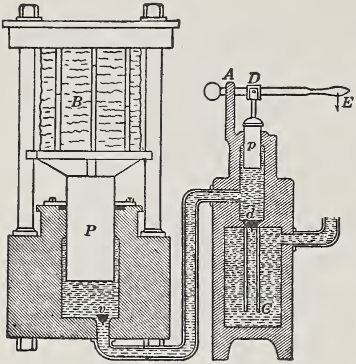


Fig. 81.—Cross Section of a Hydraulic Press

Its pressure opens the other valve at "v", allowing the water to enter the cylinder of the press, where it pushes the large ram, or working piston, up very slightly. If the large piston be 10 inches in diameter and the small piston one inch in diameter, then the area of the big one is 100 times larger than that of the little one. Of course no hydraulic press ever built gives quite as much increase of pressure as the principle would indicate. This is because some of the pressure is used up in overcoming friction.

The pressures produced by modern hydraulic presses are very great. They have many industrial uses such as extracting oil from seeds, pressing juice from beetroot in sugar manufacture, pressing cotton into bales for shipment, forcing solid lead through a die to make lead piping, stamping coins and medals, squeezing automobile bodies and fenders into shape. Lifting great weights into place is another of their uses. The central span of the Quebec bridge was built as a separate unit, floated down stream to the bridge and then lifted bodily into place by hydraulic presses. They are also used for testing the strength of boilers, big guns and great steel chains. Perhaps the most familiar applications of the hydraulic press are the dentist's and barber's chairs. Oil or alcohol is often substituted for the water in hydraulic presses, especially in countries having severe winters, as these liquids do not freeze as readily as water.

## QUESTIONS

1. In what way did the invention of the steam engine affect the use of water power as a source of power production?
2. What is meant by the "head" of a body of water? Why is this factor so important to engineers when constructing a hydro-electric generating plant?
3. Why is the development of water power resources of particular interest to Canadians?

4. Explain the use of the "stand pipe" in Figure 79.

5. Tell three ways by which municipalities obtain sufficient pressure in their water systems.

6. Make a sketch of a force pump showing clearly the action of the valves when the piston is (a) moving downwards, (b) moving upwards.

7. What property of air is made use of in the air dome of a force pump? What are two uses of the air domes of these pumps?

8. State three important differences between a force pump and a lift pump.

9. Explain the principle which enables such extremely high pressures to be obtained with the hydraulic press.

10. Give five common uses of the hydraulic press.

## CHAPTER XV

# THE COMPOSITION AND CHEMICAL PROPERTIES OF WATER

Having learned something about the way in which water behaves, we must now study its composition.

**What is Water?** As in the case of the air, we begin by finding out if water is a simple or a compound substance. This question may be quite easily settled by performing a simple experiment. One of the simplest and most striking methods of performing such an experiment is to pass a current of electricity through water contained in a suitable apparatus and note the result.

**Experiment 51.**—*To find out the composition of water.*

*Required:* An electrolysis-of-water-apparatus, 3 or 4 dry cells, sulphuric acid, splints of dry wood.

*Procedure:* Fill the apparatus with water which has been slightly acidulated with the sulphuric acid. Connect the four dry cells in series; that is, join the carbon terminal of one to the zinc terminal of another until they are joined together. Then connect the end terminals to the terminals of the apparatus. Bubbles of gas will be seen forming at each of the electrodes of the apparatus. After a time it will be noticed that the gas produced at the electrode connected with the carbon terminal of the battery has only half the volume of the gas which is collecting at the other one. When a sufficient quantity of these gases has been collected, test each by means of a burning splinter of wood.

*Observation:* 1. The gas having the smaller volume causes the burning splinter to burn more brightly. This shows that this gas is oxygen.

2. The gas having the larger volume ignites with a slight explosion and burns with a pale blue flame. This shows that this gas is hydrogen.

*Conclusion:* This experiment shows that water is composed of the two gases, hydrogen and oxygen, and that two volumes of hydrogen are united with one volume of oxygen.*

It is therefore clear that water is a compound because we can obtain two simpler substances, oxygen and hydrogen, from it.

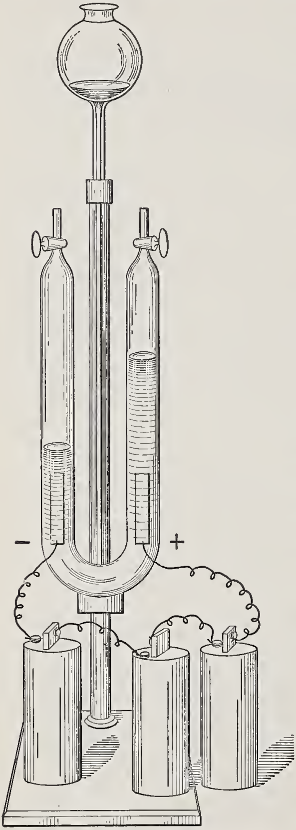


**Fig. 82.—The Electrolysis of Water**

Until late in the eighteenth century water was always considered to be an element. The circumstances leading up to the discovery that it was a compound make a splendid example of the value of observing apparently little things.

The English chemist, Priestley, who had discovered oxygen, found that a mixture of hydrogen and oxygen was explosive. He was very fond of demonstrating

*It may be suggested that, as sulphuric acid was added to the water, the gases may have come from the acid. This is not the case, for no matter how long the electric current is passed through the water the amount of sulphuric acid remains unchanged, but the quantity of water steadily diminishes. The purpose of adding the acid is to make the water conduct electricity. *Pure* water is not a conductor of electricity.

this explosion for the amusement of his friends. At one of these demonstrations Henry Cavendish, the great but eccentric English scientist, happened to be present. After the experiment, Cavendish noticed a mist formed by tiny drops of liquid on the walls of the glass apparatus used by Priestley. Later in his own home Cavendish repeated the experiment for himself, and by using the same vessel several times over he was able to collect a sufficient quantity of the liquid to prove that it was water.

Cavendish therefore concluded that water is a chemical compound composed of hydrogen and oxygen. Later Lavoisier, the great French chemist, checked up the findings of Cavendish and confirmed his conclusion.

These initial experiments of Priestley, Cavendish, and Lavoisier influenced many other investigators to make a study of the composition of water. Their work amply confirmed the discovery of Cavendish that water is a chemical compound composed of oxygen and hydrogen.

The various methods employed by chemists to determine the elements of which water is composed may all be classified under two distinct methods of attacking the problem:

1. The water may be separated into its constituent elements. This method is called *Analysis*.

2. The constituent elements may be united under certain conditions and water obtained from this union. This method is called *Synthesis*.

The experiment by which we showed that water is a compound belongs to the analytical type.

Priestley's first experiment, which led Cavendish to conclude that water is a chemical compound, belongs to the synthetic or "putting together type' of experiment.

## Effects of the Solvent Power of Water

**Air in Solution**

We have already seen that water may dissolve air and that this dissolved air is necessary for the maintenance of aquatic forms of life. It is interesting to note that air which is dissolved in water is richer in oxygen and poorer in nitrogen than ordinary air. This richer oxygen content is of the utmost importance to those forms of life which depend upon dissolved oxygen for their respiration. It must result in their being able to manage to keep up their rate of oxidation with a smaller volume of air than is required by those forms of life which utilize ordinary air.

The remarkable purifying property of water is due in large measure to the presence of air dissolved in it. Oxygen purifies water by oxidizing, and therefore destroying, the organic matter upon which bacteria feed. Their food materials being thus removed, the bacteria perish. This is the reason why many cities aerate, that is, artificially enrich, their water supply with air. The aeration is carried out by various methods, for example, by spraying the water into the air in fine jets, or allowing the water to tumble down artificial cascades before entering the storage reservoirs. Sometimes it is obtained by vigorous agitation of water in the reservoirs by mechanical devices. The refreshing taste of water is due to the presence of dissolved air. To prove this, one has only to boil water vigorously for several minutes and then allow it to cool without pouring from one vessel to another. Even when quite cold it will be found to have what is termed a "flat taste". That is to say, it has no taste at all. This is the reason why in making tea the water should be poured

on to the tea leaves as soon as it reaches the boiling point, and not, as often happens, fifteen minutes or so later. Boiled water may be made palatable again by allowing it to cool and then pouring it vigorously back and forth from one vessel to another several times. This assists it to re-dissolve air, thus restoring the pleasant taste. From this we learn a very important fact about gases, namely, that unlike most solids, they are more soluble in cold than in hot liquids.

**Alkaline Waters**

In many parts of the world, but most often in arid and semi-arid regions, the waters of some streams, lakes and wells are heavily charged with dissolved mineral matter. These dissolved minerals are principally common salt, carbonate of soda, and sulphate of soda. They impart to the water a curiously burning, bitter taste which we call "alkaline." The minerals are derived from the waste products of soil production which ordinary vegetation is unable to use with profit. In countries having a heavy rainfall and good natural drainage, these minerals are washed out of the soil by the solvent action of the water almost as rapidly as they are formed. In regions of limited rainfall, however, they accumulate in the soil, rendering it too alkaline to support vegetation. The high summer heat of such regions, by increasing the rate of evaporation of water from the soil, streams, and lakes, tends to increase the accumulation of alkali. Under such conditions deposits of white encrustations appear on the soil as it dries out, and around the margins of ponds, lakes and streams as they shrink in volume.

In Western Canada there are many of these alkaline lakes. The waters of some of them are so heavily charged with sulphate of soda that they are rapidly becoming a valuable natural resource. Their value

lies in the fact that Glauber Salt, which is only the trade name for sulphate of soda, has many industrial uses. It is used for the production of sulphate pulp, in the manufacture of plate, sheet, and bottle glass, and in the dyeing of textiles. The Dominion Government has estimated that in these lakes there are about one hundred and fifteen million tons of Glauber Salt.

**Alkaline Soils**

When the soils of a region contain unusually large amounts of these alkaline salts they are called *Alkaline Lands,* or *Alkali Belts.* There are considerable areas of such lands in Western Canada.

Soils may be rendered destructively alkaline by poor farming methods, even when natural conditions are not predisposed towards alkalinity. Intensive farming has a tendency to increase the alkalinity of the soil. Irrigation, unless carefully carried out with proper attention to drainage, is very liable to produce excessive alkalinity in soils.

Fig. 83.—Vegetation on Alkali Lands (Hilgard)

**Mineral Waters**

The term mineral water is applied to water which contains either a large volume of gases dissolved in it, or more solid matter in solution than ordinary drinking water. Such waters may be either artificial or natural.

*Artificial mineral water* is made by charging variously flavoured liquids with carbon dioxide. The industry has assumed very large proportions in recent years. Most of the so-called "soft drinks" are artificial mineral waters.

*Natural mineral waters* issue from the ground as springs. They have been found in many countries. The waters of these springs vary greatly in temperature. Some are very cold, others are warm, and many

**Fig. 84.—Geyser at Rotorua, New Zealand**

are boiling. In some cases the waters of these boiling springs are violently flung many feet into the air. Such violent intermittent hot springs are called geysers. They are known to occur only in three places—Yellowstone Park, Wyoming, U.S.A., on the island of Iceland, and on the North Island of New Zealand.

All mineral springs are heavily charged with dissolved minerals, which are deposited in considerable quantities around the mouths of the springs as they issue from the ground. Sometimes these deposits assume very fantastic and beautiful forms, which are

variously coloured according to the nature of the dissolved mineral matter. Many mineral springs have reputed medicinal properties. When a mineral spring gains such a reputation it speedily becomes a great centre of attraction. People visit it to drink its waters or bathe in its warm mineral-charged baths. Its waters are bottled and shipped all over the world to be sold to those who cannot afford to visit the spring. Examples of medicinal mineral springs in Canada are Banff Sulphur Springs, in Alberta; Radium Hot Springs, near Windermere, B.C.; Halcyon Springs, B.C.; Miette Hot Springs, in Jasper Park, Alberta; Caledonia and Preston Springs, in Ontario. The Carlsbad and Vichy Springs of Europe are world famous. The kind of mineral found in the water depends principally upon the temperature and pressure of the water, and the nature of the rock through which it has percolated. So we have iron springs, salt springs, lithia springs, sulphur springs, radium springs, each taking its name from an important mineral dissolved in its waters.

**Hard and Soft Water**

Some kinds of water are referred to as *hard,* and others as *soft.* Hard waters are those which produce a curdy, greasy precipitate with soap before yielding a lather. Soft waters produce a lather without making a curd.

**Experiment 52.**—*To find if water is hard or soft.*

*Required:* Basin, soap, distilled water, rain water, and well or "tap" water.

*Procedure:* Put some of the water to be tested in the basin. Shake some soap in the water. Do suds appear quickly? If so the water is soft. Does a whitish scum form on the water before the suds appear? If it does, then the water is hard. Try each of the different sorts of water in this manner. Which of them are hard, and which soft? Try the water at your home in this way. Is it hard or soft water?

It will be found that distilled water and rain water are soft waters, because they require little soap to produce a permanent lather. Well or tap waters usually require more soap, some of them very much more, to produce a lather which is permanent.

The question at once arises, What makes the well or tap water hard? We know that distilled water is pure water, and that rain water is the purest form of natural water. The above experiment tells us that both are soft waters. This seems to indicate that hardness in water is due to the presence of something dissolved in the water.

**Cause of Hardness in Water**

Careful investigations by chemists have shown that only certain minerals have the property of causing hardness in water. These are the *magnesium and calcium minerals.* So, though it is quite correct to say that all hard waters contain dissolved minerals, it is by no means correct to state that all waters containing dissolved minerals are hard. The hard waters are divided into two classes:

1. Those which have *temporary hardness.*
2. Those having *permanent hardness.*

*A temporary hard* water is one which may be softened by boiling. This form of hardness is caused by carbonates of calcium and magnesium being held in solution as bicarbonates by the carbon dioxide in the water. Boiling the water expels the carbon dioxide, and so causes the calcium and magnesium carbonates to drop out of solution. This accounts for the deposit known as "scale" in kettles and pans. In using a temporary hard water for industrial purposes, such as steam raising, wool scouring, dyeing, this scale becomes a nuisance, and so the water is softened in another way. One of the most common and cheapest

ways of softening a temporary hard water on a big scale is by using *milk of lime.* This *milk of lime* combines with the bicarbonate of lime or magnesia and turns into carbonate. The carbonate, being insoluble in the water, falls to the bottom and is filtered out before the water is taken into the boilers.

*A permanently hard* water is one which cannot be softened by boiling, but must be treated with some softening agent. This kind of hardness is produced by the presence of sulphates of calcium and other salts of magnesium and calcium that will dissolve in water. Boiling the water has no effect. In fact it increases the hardness, because in the evaporation of some of the water the remainder receives the mineral content. There are five common softening agents which can be used with permanently hard water: carbonate of soda, caustic soda, borax, ammonia, and washing powders. Of these, carbonate of soda is easily the most convenient and cheapest to use.

**Experiment 53.**—*To show the effects of carbonate of soda (washing soda) on a permanently hard water.*

*Required:* A sample of permanently hard water, carbonate of soda, soap solution, spirit lamp.

*Procedure:* If a sample of permanently hard water is not available dissolve 0.1 gram of calcium sulphate (gypsum) in 500 c.c. of distilled or rain water.

1. To 25 c.c. of this water add a small crystal of carbonate of soda and boil.

2. Determine the amount of soap solution necessary to make a lather lasting two minutes.

3. Determine how much soap solution is necessary to produce a similar lather with 25 c.c. of the distilled or rain water.

4. Boil some of this distilled or rain water for several minutes and then test with the soap solution.

Tabulate the results and compare them. Does boiling soften a permanently hard water? What is the effect of the carbonate of soda?

**Hard and Soft Water Compared**

*Hard water*—One of the great objections to hard water is that it is very wasteful of soap. The amount of soap wasted annually by the use of hard water is stupendous. It has been estimated that a family of seven, using an average hard water, wastes one hundred and sixty pounds of soap a year. One may thus form some idea of the great annual wastage of soap throughout the world. Also, the production of the curd with hard waters increases the labour of the household, since it leaves greasy deposits in the wash bowls, entailing extra work to keep them clean. Clothes which are washed in hard water are always harsh to the touch and somewhat dingy in appearance, because the curd made with the soap clings to the fibres and cannot be removed by the ordinary rinsings given in a household laundry. The scales and deposits produced by hard water are very detrimental to the machines used in industrial plants. These deposits also absorb a lot of heat and thus increase the fuel bills in such plants.

*Soft water* is preferable for many reasons among which may be stated that:

1. It produces a lather quickly and copiously, thus saving soap.
2. It dissolves greases and sticky matters more easily than hard waters, and so is much better for washing purposes.
3. It is of much greater value in keeping the skin in a healthy condition.
4. Meat and vegetables are better when cooked in soft water. Hard waters impart their hardness to the food and destroy the taste.
5. Soft water does not produce "scale" to clog up the plumbing fixtures.

## QUESTIONS

1. Describe an experiment to show that water is a compound.
2. How does oxygen purify water?
3. Account for the "flat" taste of boiled water.
4. What are "alkaline waters"? What valuable natural resource is awaiting development in the alkaline lakes of Western Canada?
5. What is an "alkaline soil"? Mention three ways by which a soil may be rendered destructively alkaline.
6. What is a mineral water? Why are natural mineral waters often a valuable natural resource?
7. Distinguish between hard and soft waters. How would you determine whether a sample of water is hard or soft? How would you make hard water soft?
8. What are the disadvantages attending the use of hard water for domestic purposes?
9. Explain the difference between temporary hard water and permanent hard water. Name four household materials which may be used to soften hard water.

## CHAPTER XVI

## RELATION OF WATER TO PLANTS

Everyone knows that for a plant to live and thrive it must have a carefully regulated supply of water.

**Importance of Water to Plants**

It is common knowledge that lack of water causes plants to wilt. It is equally well known that an over-supply of water is injurious to plant life. The water is required by the plant for many purposes:

1. To keep the protoplasm of the cells at the correct degree of moisture for active work.
2. To be manufactured into sugar and starch, by the process of photosynthesis in the leaves of the plant.
3. To dissolve food materials so that they may enter into, and nourish, the cells.
4. To transport materials from one part of the plant to another.
5. To impart rigidity to the tissues by filling the cells with water, thus preventing wilting.

*Amount of water required*—The quantity of water needed by various kinds of plants to ensure healthy growth and the production of good seed varies very greatly. It depends upon several factors, the chief of which are the weather conditions, the food supply, and the variety of plant.

The securing of the necessary water and the careful regulation of the amount permanently retained in the plant tissues, are brought about by very interesting and ingenious adaptations of the roots, stems and leaves of the plants.

*Absorption of water and dissolved materials*—The roots of plants have two important functions:

1. To hold the plant firmly in place.

2. To secure the water and dissolved plant food from the soil.

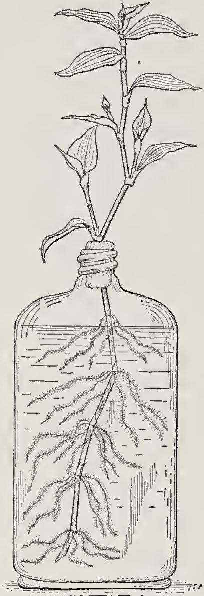


Fig. 85.—Cutting of Wandering Jew in water, showing root hairs which increase the absorbing surface from fifty to seventy-five times; in order to get an equal surface without root hairs each of these roots would have to be from one to six inches in diameter.

Practically all the water taken in by plants enters through the root system. The food material gathered by the roots must be dissolved in the soil water before it can enter the plant.

**The Root System**

The root system of the plant consists of four distinct parts, the main root, the rootlets, the root hairs, and the root cap. All the absorption of water and food materials is accomplished by the root hairs. That this is true may be shown quite simply. Pull up a young seedling, taking care not to loosen the soil which clings to its roots. Properly transplant it in another place and water it thoroughly. It will continue to grow, apparently having suffered little or no injury. Now select another seedling, which appears to you to be equally vigorous and about the same size. Pull this

up and remove the soil particles that cling to its roots. In doing this you will remove many of the delicate root hairs, and many others will dry up through being exposed to the air for too long a period. Now transplant this seedling and water it. It may recover after a long struggle, but it will most likely wither and die even though well watered and cared for. This shows that the root hairs are the adaptations by which water and soil minerals enter a plant.

Another important function of the root hairs in their absorption of water is that their large numbers greatly increase the absorption surface of the root system. Osterhout states that in the case of the Wandering Jew cutting, shown in Fig. 85, the root hairs developed increased the absorbing surface from fifty to seventy-five times and, "to get so much surface without the device of root hairs, each root would have to be from fifty to seventy times thicker, i.e., from an inch to five or six inches in diameter." (Osterhout, *Experiments With Plants,* Macmillan, pages 102 and 103.)

**How the Root Hairs Absorb the Water**

The root hairs are very delicate thread-like sacs which grow near the ends of the rootlets. They never grow right at the end, because this is covered by a growth of cells called the root cap. The function of the root cap is to protect the delicate tip of the root as it finds it way between the soil particles. As the rootlet penetrates into the soil, the root hairs cling to the soil particles. These particles are surrounded by a film of capillary water and air spaces. The fluid in the root hairs is a denser solution than the water clinging to the soil particles. Therefore we have all the requirements for *osmosis* to take place. Each root hair is in fact a tiny little osmotic apparatus, by

which the plant absorbs its water and dissolved mineral food.

*Conveyance of water through root, stem, and leaf*—In our study of photosynthesis, we learned that water was continually being brought into the leaves. We have just seen that all, or practically all, of this water is collected from the soil by the root hairs. How does the water reach the leaves? It is quite clear that it must pass through the stem, since there is no other connection between the roots and the leaves. In what manner does the water travel? Does it pass through the entire tissue of the stem or does it travel along definite channels? This question may be answered by performing a simple experiment.


**Fig. 86.—Distribution of water on the surfaces of soil grains and of root hairs.** e, main root; 1, air-space; 2, soil grain; 3, film of water; hh, root hairs. (After Sachs.)

**Experiment 54.**—*To find out if the liquids in the plant travel along definite channels or if they pass through the entire stem tissue.*

*Materials:* Red ink, tall jar, stalks of celery and geranium, or some such similar plant material.

*Procedure:* Place some water in the jar and colour it a bright red with red ink. Trim off the bottom ends of the stalks of whatever plant material you have been able to obtain. Place the stalks in the jar with the cut end well below the surface of the red ink water. Leave in some place favourable for evaporation for about two or three hours, or overnight. After this period remove the stems from the ink solution, and thoroughly wash them. This is to remove the surface stain. Cut off transverse sections of the stems and examine them. It will be seen that the red colouring matter is not diffused throughout the tissue, but is confined to definite spots. Next take one of the sections and cut down longitudinally through one of the red

spots. A definite red channel will be found. With care these channels may be removed and examined. They are bundles of tubes called fibro-vascular bundles.

These bundles of tubes are found not only in the stems, but also in the roots and leaves of the plant.

**The Fibro-vascular Bundles**

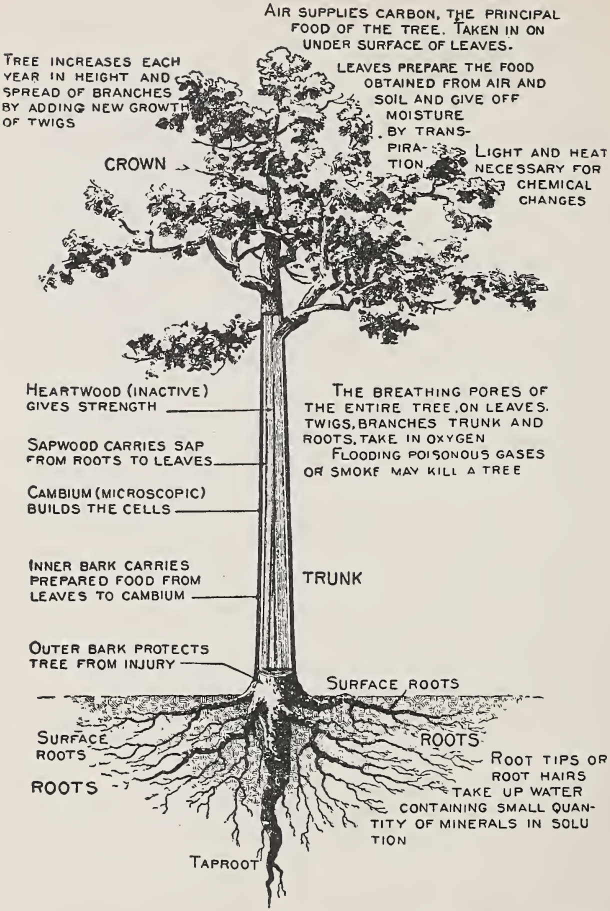
There are two distinct sets of them in every plant. One set is used to carry water containing dissolved minerals from the roots to the leaves. This set of tubes forms the sap wood, and lies nearest to the centre of the plant.

The other set of tubes is called *sieve tubes*, because the vessels composing them are separated from each other by perforated plates called *sieve plates*.

The function of the "sieve tubes" is to carry the food manufactured in the leaves to the various parts of the plant, to feed the living cells, and to be stored as starch or converted into "woody tissues" and assimilated into the plant body. This set of tubes forms the inner bark and makes a continuous series of canals from the leaves through the leaf stalks, twigs, branches, and stem to all living tissues of the plants. Should the inner bark become injured, say by ringing or by constriction, the plant will sooner or later die. This is because those parts of the plant below the injury cannot obtain food, and so they starve to death.

In all plants a complete new set of both kinds of tubes is built each year. In the case of trees like the poplar, birch and spruce, the old tubes are absorbed into the heart wood of the plant and form the annual rings by counting which the age of the tree may be computed.

In very large trees such as the Douglas fir, the water taken in at the roots has to be elevated to a height of more than 275 feet. To do this requires




(*From Brownell's General Science.*)

**Fig. 87.—Structure of tree, and functions of its parts**

the exertion of considerable force. Just how this force is developed is not definitely known. It is one of the great mysteries of plant life. There seems to be little doubt, however, that it is the result of several forces at work in the plant. Among these we may distinguish three that most certainly have some effect in moving the water up to the top of the tree. These are:

**What Makes the Sap Rise?**

1. Root pressure, due to the osmotic action of the root hairs.
2. Capillarity in the fine tubes of the xylem vessels.
3. Leaf suction due to the rapid evaporation of water from the leaves.

Many careful and distinguished botanists think that even the combined effects of these forces are not sufficient to account for the ascent of the sap in very big trees. Others equally careful and competent consider that no other explanation is necessary. The whole question is very difficult, and it must be admitted that no entirely satisfactory explanation of the ascent of sap has yet been made.

*Osmotic action* is of great importance to plants. By it they secure food materials from the soil and from the air. Osmotic action is one of the principal forces contributing to the circulation of sap. It is the fluid pressure, produced by osmosis, which, distending the cells of the living plant, gives the necessary stiffness to support the softer parts of the plant body.

*Evaporation from the leaves*—We have seen that the root hairs are incessantly passing water into the plant. Only a small proportion of this water is retained in the tissues or converted into food. What becomes of the excess water? Clearly the plant must dispose of it in some way. If it did not, the accumulation of

water would soon burst the cells and cause the plant to die.

**Experiment 55.**—*To find out if plants pass out water through their leaves.*

*Required:* Two fruit sealers, a quantity of plant leaves or several leafy shoots from fresh plants, two saucers or plates, vaseline.

*Procedure:* Make sure that the sealers are dry and that the leaves have no free water upon them. Place the leaves or leafy shoots in one of the sealers, and place the mouth downward on the saucer or plate; carefully seal the rim of the sealer to the plate with vaseline so as to prevent the entrance of any outside air. Next set up the other sealer in exactly the same manner, but do not place any leaves in it. The purpose of the empty sealer is to enable a comparison to be made.

*Observation:* In about half an hour a thin film of moisture will be seen on the inner surface of the sealer containing the leaves. The other sealer shows no such film. If left for several hours the water will collect in drops on the walls and top of the sealer containing the leaves. The empty sealer remains quite clear.

*Conclusion:* From the observations above we conclude that the leaves are constantly passing water into the air in the form of water vapour.

**Transpiration**

The passing of water vapour into the air by the plant is called *Transpiration.* It takes place mainly through the stomata of the leaves, but some water is also lost through the lenticels and the skin of the leaves and twigs.

Although transpiration is absolutely necessary to the well-being of plants, its rate must be carefully controlled lest it become a menace instead of a benefit. If the rate of transpiration, from any cause, should become greater than the rate of absorption of water, the plant wilts. That is to say that cells stretched tight by the fluid pressure within them become soft, flabby, and shrunken. They are thus rendered incapable of supporting the weight of the plant. The condition operates strongly against food manufacture and sap

circulation, the result being that the plant dies from lack of nourishment.

*The rate of transpiration* is very strongly influenced by:

1. The condition of the atmosphere.
2. The amount of water in the soil.
3. The concentration of mineral salts in the soil water.
4. The amount of leaf surface exposed by the plant.

The action of the atmosphere on the transpiration rate is directly in proportion to its power of evapora-

**Fig. 88.—To Illustrate Transpiration**

tion. Therefore any atmospheric condition which will increase the rate of evaporation will also result in an increase of the rate of transpiration. Hot, dry winds result in plants transpiring at an excessive rate, be-

cause the heat raises the moisture-holding capacity of the air, and the wind is constantly removing the moisture-laden air and replacing it with fresh dry air. Hot, sunny days tend to cause rapid transpiration by increasing the moisture-holding power of the air. Windy days, even at low temperatures, always increase transpiration by exchanging the air over the leaves.

*The amount of water in the soil* influences the transpiration rate, by governing the speed at which water may be passed into the plant. Plants growing in wet soils transpire far more rapidly than those in drier ones.

*The concentration of mineral salts in the soil water* may, during periods of drought, result in the solution outside the root hairs becoming more dense than the sap solution inside them. Such a condition results in a reversal of the osmotic flow, causing water to leave the plant. The plant tries to offset this by reducing its rate of transpiration.

*The extent of leaf surface exposed*—Since most of the water is transpired through the leaves it is obvious that an increase in the leaf surface must speed up the transpiration rate. This is one reason why plants in shady, damp places have larger leaves.

**How Transpiration is Controlled**

Too rapid transpiration is of grave danger to the plant; many devices have therefore been developed by them for the regulation of its rate. Ordinarily the plant controls its loss of water by means of the guard cells of its stomata. These are called guard cells because they regulate the amount of water transpired by opening or closing the stomata. Often, however, conditions arise when the action of these guard cells cannot sufficiently control

the loss of water. The plant then develops various other devices for the retention of the precious water. The most important of these special devices are:

1. Reduction of amount of foliage.
   - (a) By making smaller leaves.
   - (b) By production of fewer leaves.
   - (c) By dispensing with leaves entirely.

Examples of this method are to be observed in any dry place. In arid lands the small number of leaves on the trees produces a curiously spotty look to the landscape. Cacti are examples of plants which have dispensed with leaves entirely in their efforts to conserve water.

2. Altering the structure of the leaf.
   - (a) By thickening the skin.
   - (b) By reducing the number of stomata.
   - (c) By introducing storage cells in the leaves, branches and stems for the holding of water.

As examples of plants adopting this method of combating excessive loss of water we may note the cacti, ice plant, live-for-evers, and century plants.

3. Maintaining a fixed position of the leaf to the light. This causes the edges of the leaves only to be presented to the hotter noonday rays and the flat surfaces to the cooler morning and evening rays. The compass plant of the prairies is a common example. Gladioli and iris are familiar garden plants using this method. In Australia, which is the driest of the continents, the gum or eucalyptus tree makes use of this device.

4. By the production of motile leaves. This device gives the plant the power of folding or rolling up its leaves, so that, as occasion demands, a greater or lesser amount of leaf surface may be exposed. Corn plants and many grasses are examples of plants which roll

their leaves. Clovers and wood sorrels are plants that fold their leaves.

5. By growing a hairy or woolly covering on the leaf. This prevents evaporation by interposing an effective heat screen between the water issuing from the stomata and the atmosphere. Common Canadian examples, especially in the prairie dry belt, are wormwort, sage, Labrador tea, crocus and anemone.

6. By producing a waxy or gummy covering on the leaf. The sticky leaves and buds of the balm of Gilead, birch and spruce, are examples.

So far we have been considering devices for the prevention of water losses. In many localities, however,

**Hastening Transpiration**

water is so plentiful and evaporation so slow that the plants inhabiting these places are faced with the problem of hastening transpiration. Such conditions occur most frequently in the hot, steamy forests and jungles of the equatorial regions. In such places certain trees leak water so fast that it drips from long pointed tips on the leaves called *drip tips*. The leaves of the plants in such regions are generally large and are provided with stomata in about equal numbers on both sides of the leaf.

Whether it be desirous of retaining or of losing water gradually by evaporation, or of expelling an excess of it, each species of plant has developed the device best suited to preserve its individual life under the conditions in which it must live.

*Water as a constituent of plant tissue*—Water is present in plant tissue in two forms, free, and combined. The presence of free water in plant tissue may be demonstrated by the following simple experiment.

**Experiment 56.**—*To show that water is present as such in the tissues of plants.*

*Required:* Some green leaves of any plant, a carrot to represent a root, and some kernels of wheat or corn as samples of seeds. Enamelled saucers, glass squares to cover.

*Procedure:* Place some of each kind of material in separate dishes. Cover with the glass covers and set aside in a warm place.

*Observation:* In about 10 to 15 minutes examine them. The glass covers will be dimmed with moisture that has been driven out of the plant materials by the heat. This shows that free water is present in the plant materials. The cover over the leaves will have the most moisture condensed on it, that over the seeds the least.

*Deduction:* From the experiment we conclude that free water is present in all plant tissues, but varies very considerably with the kind of plant and particular tissue. Careful experiments have shown that leaves contain about 80 to 90 per cent. of water; roots very nearly that amount; seeds from 10 to 15 per cent.

Combined water is water that has united with other substances to form new compounds. Every tissue of the plant body contains considerable amounts of water in this condition. It is not very easy to show this combined water because, when we decompose the tissue, other substances like wood tar are liberated at the same time. However one of the principal materials found in most plant tissues is starch. This consists of carbon combined with water. It is easy to extract the combined water from starch.

**Experiment 57.**—*To show that one of the constituents of starch is water.*

*Required:* Some lumps of dry starch, test tubes and spirit lamp.

*Procedure:* Carefully dry an empty test tube in the flame of the spirit lamp. Put a lump of dry starch into the tube and heat over the flame of the spirit lamp.

*Observation:* After heating a few moments examine the starch and note that it is changing to a brown colour. Next note that the inner sides of the tube are dimmed with water vapour condensed on them. Continue heating until the starch turns black. The blacker the residue becomes the greater the amount of moisture collected on the cool part of the tube. The drops of moisture, if tested, will be found to be water.

It is therefore evident that, since most plant tissues contain starch in one or other of its various forms,

combined water must be an essential part of plant tissue.

## QUESTIONS

1. State four ways in which water serves the growing plant.
2. Give five examples of bodily structure of plants dependent upon the plant's use of water.
3. Indicate four different devices by which plants regulate evaporation from their bodies.
4. What are the functions of the roots of plants?
5. What are root hairs? Explain how they absorb water.
6. What makes the sap rise in plants?
7. What is transpiration? Describe an experiment which illustrates transpiration by plants.
8. Write an account of the value of osmotic action to plants.
9. What factors strongly influence the rate of transpiration by plants?
10. Show by experiments (a) that water is present as such in the tissues of a plant, (b) that water is a constituent of starch.

# CHAPTER XVII

## DRINKING WATER

Wherever man travels or settles he must be assured of a supply of water. The task of securing ample supplies of wholesome water is always one of the greatest problems facing a community.

Under modern conditions the ease with which we, as individuals, obtain water is apt to make us underestimate the difficulties and true importance of the problem. For one thing, the magnitude of the task is far greater than most people realize. The amount of water which must be collected, treated, and distributed each day to the dwellers in a modern city is stupendous. It is quite safe to say that hardly one adult person in ten has any idea of the amount of water which our Municipal Governments must supply daily. But this is not the end of the problem. In addition to the huge quantity of water distributed, the strictest attention must

**Problems of Supply**

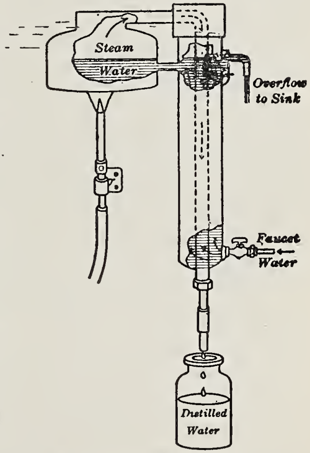



Fig. 89.—Purification of Water by Distillation

be paid to the character of the water which is supplied.

The very nature of water makes it a most difficult commodity to keep in a safe state for any length of time. On all sides there are lying in wait a host of conditions, any one of which may render the water supply unsafe. The safeguarding of the water supply is one of the great sanitary problems of the day. Only the most unremitting care and attention to the minutest details can prevent the pollution of the water supply of a community, and the consequent outbreak of epidemic diseases like typhoid and cholera.

**Quantity of Water Required**

Water makes up rather more than three-quarters of the entire weight of the human body. An average-sized man loses daily through the skin, lungs, and kidneys, about 80 ounces of water. The water to replace this loss is obtained through the solid food and beverages taken, roughly in the following quantities: about one-third from the water contained in solid food, and the balance, about two and a half pints, in the form of water or other beverages. Next, about one gallon per person is required for the washing of the hands and face. For bathing, another fifteen gallons per person is required, and the amount required for laundry, cleaning, and other domestic purposes brings the total to about 25 gallons in all.

Besides all this must be allowed the water necessary for fighting fires, removing sewage, sprinkling and cleaning streets, and for industrial requirements. Altogether, a great modern city will require about 100 gallons of water per head of population every day.

The City of Toronto consumes 50,000,000 gallons daily. Montreal, through the Municipal Water Works and the Montreal Water and Power Company, sup-

plies 81,000,000 gallons of water every 24 hours. Winnipeg uses over 30 million gallons. Edmonton supplies 10 million gallons each day. Calgary uses 12 million gallons daily. Vancouver requires approximately 20 million gallons. These are enormous totals, but they are small beside those of such great centres as London, New York, Chicago and Paris.

**Sources of Water**

The water for community purposes is obtained in various ways, but usually from rain, snow, ice, streams, lakes, ponds, wells, or from collected surface rain water. Under certain extreme circumstances, it may be obtained by distilling sea water, but this is so expensive a method that it is not a common practice. Rural districts and small communities usually depend upon wells or springs. Towns and cities usually obtain their water from rivers or lakes, and sometimes from deep artesian wells. They do not often depend on wells or springs for two reasons:

1. It would be difficult to obtain a sufficient supply from such sources.

2. The soil of cities and towns becomes so contaminated with waste materials that the water from shallow wells would speedily become unfit for use.

**Good Drinking Water**

A good drinking water should have the following characteristics:

1. It should be colourless.

2. It must have no odour.

3. It must have a pleasant taste and be well aerated and sparkling from the dissolved air and gases.

4. It should be soft and dissolve soap easily.

Having located an adequate supply of wholesome drinking water and provided for its delivery to, and distribution through, the community, the municipality

or waterworks company is by no means at the end of its troubles. The high solvent power of water and the consequent ease with which it may be contaminated require the strictest care to prevent the water supply of a community from becoming a source of grave danger to the consumers. From the standpoint of public health, the impurities of a water supply may be classified as gaseous, organic, and mineral eral.

**Impurities in a Water Supply**

*Gaseous impurities*—The gaseous impurities are chiefly oxygen, nitrogen, and carbon dioxide. These can hardly be considered as impurities since upon them depends the pleasant taste and sparkling appearance of the water.

*Organic impurities*—These may be either suspended in the water or dissolved in it. They can be of either animal or vegetable origin. Both classes are very serious impurities for they may, and often do, cause serious epidemic diseases. When present in even minute quantities in the water, they render it unfit to drink. Water containing such material is called "polluted water". The principal danger of such pollution is that it is often the vegetable or animal matter of manure swept into the water supply by surface water. It may be due to actual sewage matter, which has found its way into the water.

*Disease germs* are another type of organic impurity. The germs of typhoid fever, cholera, dysentery, and diphtheria are very frequently introduced into water with air and the other gases which it dissolves. More often they find a way into drinking water by leakage from sewers, drain-pipes or privies.

*The mineral impurities* do not generally render the water unfit for drinking purposes. Mineral impur-

ities may be either suspended or dissolved in the water. The principal objection to them is that they make the water hard. This has already been noticed, and its general effects considered, in Chapter XV.

All or any of the above impurities may enter the water supply at any of the following points, viz.,

1. At the source of the supply.

2. During transit from the source to the town or city.

3. During distribution through the water mains, or other means of distributing the water to each consumer.

4. During storage prior to distribution, or at the point of consumption.

All methods for the purification of water may be considered under two heads; namely, Natural and Artificial.

**Purification of Drinking Water**

*Natural methods of purification*—It has long been known that water contaminated with organic matter tends to purify itself when exposed to the air and sunlight. This is because air is soluble in water and the resultant dissolved oxygen, assisted by the presence of certain bacteria, slowly oxidizes any organic matter present in the water. When this happens, the organisms present in the water die for lack of food. Sunlight, also, kills bacteria. Again, in the passage of water through the rocks or beds of sand, much of the suspended matter is filtered out of the water. Large bodies of still water give the sediments an opportunity to settle. All these things working together contribute to the self-purification of water.

*Artificial purification of water*—The natural means of water purification are slow. Therefore they can-

not be relied upon for the rapid purification of the immense quantities of water distributed daily to large communities. Artificial methods are then used in the waterworks of towns and cities.

*Domestic water* can be rapidly purified in many ways. If the quantity required be small, it may be distilled or boiled for a sufficient length of time to kill the bacteria. But either of these methods is far too expensive to be used for the purification of a city supply. The chief methods used for large-scale, rapid purification are aeration, sedimentation, filtration, and chlorination.

In aeration, the water is sprayed into the air and the dissolved oxygen oxidizes the food of the bacteria. Sometimes aeration is accomplished by allowing the water supply to discharge down an artificial cascade into a storage reservoir. Aeration by itself, however, is not a very certain method of purification.

The most common method is a combination of sedimentation, filtration, and chlorination. In this method, the sedimentation is hastened by the addition of alum. The action of the alum is to unite with the water to form a gelatinous substance, which catches and holds the small particles of suspended organic matter with which it comes in contact. These rapidly become large enough to settle to the bottom of the sedimentation basins. The water is then drained off and passed through filters.

The filters used are of two main kinds, namely,

**Filters**
1. Sand Filters.
2. Mechanical Filters.

*Sand filters*—When large quantities of water are being dealt with, as in the case of large cities, extensive and very costly filter beds consisting of successive layers of gravel, coarse and then fine sand, and

sometimes an upper layer of charcoal, are constructed. These beds have several disadvantages; for example, the water passes slowly through them. The filtering materials require to be dug up and cleaned in special apparatus designed for the purpose. This involves considerable expenditure of time and money. They are being gradually replaced by the more rapid and convenient mechanical filters.

*Mechanical filters*—This type of filter consists of a wooden, or, better, steel tank, fitted with an overflow rim at the top and a grating near the bottom. It is equipped with a power driven apparatus for cleansing the filtering materials. The filtering materials consist of layers of sand and fine gravel, and sometimes charcoal. These lie on the top of the grating. The impure water enters at the top, and, passing through the filtering material, emerges at the base in a clear and usable condition.

The filter requires cleaning about every 24 hours. This is rapidly accomplished in a few minutes by operating the stirrers, and admitting a reverse current of water. The whole of the filtering material and the impurities collected therein are thus violently agitated, and the particles of dirt washed away, leaving the material clean and available for further action. Mechanical filters have the great advantages of speed, practically continuous operation, and simplicity.

*Chlorination*—The two operations of sedimentation and filtration remove all the suspended inorganic impurities and most of the germ life from the water. There are, however, many forms of germ life, dangerous to public health, which are not removed by these processes. These are removed by treating the water with chlorine gas, which is very fatal to germ life. This is done by injecting liquefied chlorine into the

water just before it enters the distribution system. The amount required is extremely small and imparts no unpleasant taste or danger to the water supply.

The whole treatment of the water is under the care of experts, who, by means of daily analysis and bacteriological examination, regulate the details of the treatment.

## QUESTIONS

1. Discuss the statement "The very nature of water makes it a most difficult commodity to keep in a safe state for any length of time".
2. Give an account of the chief impurities likely to be found in the water supply of a community under the heading (a) mineral, (b) animal, (c) vegetable.
3. What are the characteristics of good drinking water? From what sources is such water obtained?
4. How may water supply become polluted?
5. Describe the method used for the purification of a city or town water supply.
6. Why do cities seldom depend upon wells as a source of water for domestic use?

## CHAPTER XVIII

## WATER IN RELATION TO INDUSTRY AND COMMERCE

Water is needed by man for five main uses, Domestic, Municipal, Industrial, Commercial, and Irrigation.

**Usefulness of Water**

The domestic uses of water include drinking, cooking, washing, bathing and gardening.

The municipal uses comprise the disposal of sewage, the sprinkling and cleaning of streets, fire protection, the supply of drinking fountains, and the provision of swimming baths.

The relation of water to these uses has already been discussed, but it remains to consider the industrial and commercial use of water.

**Water in Industry**

The industrial use of water are many and varied, and the quantity required by the modern industrial world is enormous. One of the chief industrial uses of water is for the production of steam, to supply energy for the operation of great industrial plants. Pulp and paper manufacturing require tremendous amounts of water. In this industry the main function of the water is to transport the fine pulp fibres from the mechanical grinders or steam digesters to the great paper-making machines.

The water is also used to remove impurities and to bring the bleaching materials in close contact with every particle of the pulp. It is stated that the production of one ton of paper requires the use of from 10,000 to 40,000 gallons of water.

Water is also a basic requirement in dyeing and bleaching. It is also used in large quantities in the making of leather, the washing of wool, and the preparation of all kinds of textile fibres for spinning. The manufacture of beverages such as soft drinks demands the use of large supplies of suitable water. Again, the extraction of many metals from their ores is accomplished by the use of huge amounts of water. Many mining operations, dredging for gold for example, depend entirely on the use of water. The great packing plants and their allied industries are great consumers of water. Most of the great chemical industries need ample supplies of water for their successful operation.

**Importance of Water Power to Industry**

Perhaps the greatest industrial development of our times is the utilization of water power for the production of electricity, and the long distance transmission of the power so obtained. One of its most important effects would seem to be the possibility of its altering the centres of the world's industries. This is because hydro-electric power is cheap and industries always tend to move towards cheap power.

This possibility is of great significance to Canadians in the building up of the new industrial Canada.

The water power resources of Canada are wonderful and her situation with respect to the world's markets unsurpassed. Already Canada has made rapid progress in the development of her water powers for hydro-electric power purposes. To-day she is in the van of progress in the electric industry. It is interesting to note that, with respect to hydro-electric energy, Canada has larger resources and at present

larger installation of plants than any other country in the world, except the United States.

During the last ten years the rapid development of Canadian water powers for hydro-electric energy has resulted in the establishment of many industries, and has facilitated the great mineral development of Northern Ontario and Manitoba.

**Irrigation**

One of the very important uses of inland waters is for irrigation. By means of irrigation great areas of what would otherwise be unproductive land are brought under cultivation, and thus enabled to supply dense populations. This fact was well understood by the Ancients, whose great irrigation projects still excite our wonder. In modern days the pressure of population and the increased demand for raw materials for industry have compelled a renewed interest in irrigation. Modern irrigation works are on a gigantic scale. India, Egypt, the United States, Australia, China, Canada, Argentina, and British South Africa, all have, and are still carrying out, great irrigation schemes. In all these countries vast areas of hitherto unproductive land have been brought under cultivation.

Of all these the irrigation projects of the Indian Empire are without doubt the most famous. The Chenab Irrigation Project of Northern India and the Sukkur Barrage on the Indus in Sind are easily the greatest irrigation works in the world. The Sukkur Project when completed will, it is expected, reclaim six million acres of desert land. Altogether the irrigated land in India amounts to more than 50 million acres.

In Egypt irrigation has been practised from very early times. During the British occupation modern irrigation works were constructed. The most impor-

tant of these are the great dams at Aswan and Assiut.

In the Anglo-Egyptian Sudan, the works at Sennar on the Blue Nile rank as one of the world's greatest irrigation enterprises. In the United States about eight million acres are at present under irrigation, with plans laid to irrigate something like 30 million

**Fig. 90.—Bassano Dam, Eastern Section, C.P.R. Irrigation Block, Southern Alberta**

acres. The Salt River Project and the Roosevelt Dam take rank as irrigation works of first class importance. In Australia great tracts of land in the Murray-Darling Basin have been converted from desert lands into fine fruit-growing districts. The Riverina and the Mildura Districts are good examples.

Irrigation is practised in Canada in British Columbia and in Southern Alberta. The Canadian Pacific Railway Irrigation Block, in Southern Alberta, is one of the largest individual irrigation projects on the continent of America. The Bassano Dam in the Eastern section is the main feature of this project. Other important irrigation schemes in Southern Alberta are the Lethbridge Irrigation Block, the Taber Irrigation

Block, and the Canada Land and Irrigation Company's project.

Besides wheat, the products of the irrigated lands of Alberta are sweet corn, squash, watermelons, tomatoes, cucumbers, field peas, brome and timothy grasses, sugar beet, barley, flax, alfalfa, and vegetables.

The British Columbia projects lie mainly in the Okanagan Valley, where fruit is the main product, apples, peaches, pears, plums, cherries, raspberries and strawberries, being principally produced. Considerable dairy farming is also practised on these irrigated lands.

The most important effects of irrigation are:

1. It reduces the risk of famine in congested areas such as India and China.

2. It affords relief to over-pressure of population.

3. It increases the supply of raw materials for manufacturing industries.

4. It increases the world's wealth.

5. By successive deposits of silt, it tends to maintain the fertility of the soil.

**Relation of Water to Commerce**

Commerce is that wonderful organization of industry by which surplus products of nations are exchanged. One of the greatest branches of commerce is transportation. Cheap transportation is the life blood of all industry. Without it all our modern system of manufacturing and the distribution of its products would be impossible. Cheap transportation, more than anything else, has made possible the development of national and world-wide markets.

Transportation by water is by far the cheapest form of transport. The greater part of the com-

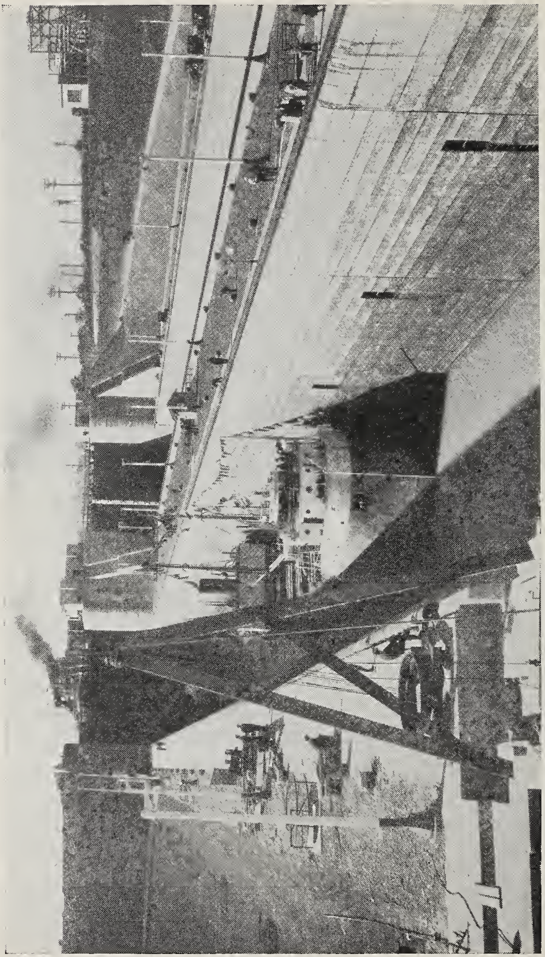


**Fig. 91.—A Lock on the Welland Canal, Welland, Ontario**

merce between nations is accomplished by some form or other of ocean transport. Besides this foreign or external commerce of nations, a very great deal of the inland transportation of countries is accomplished by means of rivers, lakes, and canals. In many countries the transportation on inland waters far exceeds that carried by railroads and other land routes. The great importance of water to commerce is well shown by the fact that most of the world's greatest commercial cities are located upon some sort of waterway, ocean, lake, river or canal.

One of the finest examples in the world of the importance of water to commerce is that afforded by the St. Lawrence River. The value of this great waterway to Canada and to the United States is enormous. In combination with the Great Lakes it furnishes a route of about 1,700 miles, tapping the great agricultural resources of the interior. It also affords cheap transport for the iron ores mined around the western end of Lake Superior. Then again it gives similar facilities for the exploitation of the lumber and pulp resources of this region.

In the early stages of the development of most countries the inland waterways play a very important part. This is because they afford a ready-made road by which traders and settlers may penetrate far inland. There are few better examples of this than in the early history of Canada.

Again, the importance of water to commerce is displayed in the immense sums spent on, and the wonderful engineering skill shown in, the construction of canals. Consider in this respect the value of such canals as the Suez, Panama, Welland Ship, Manchester Ship and the three "Soo" Canals. Perhaps the most important canal enterprise of the present day is the

Canadian Welland Ship Canal, which has recently been completed.

Another important use of water in commerce is its application to refrigeration. The modern development of refrigeration and its application to transport are among the greatest benefits of the age. Refrigeration has made it possible to distribute to the dense populations of our industrial and commercial cities immense quantities of fresh foods, such as fish, meat, eggs, dairy products, vegetables, and fruits. In addition it has created the great chilled meat industry of Australia, New Zealand, and Argentina in the Southern Hemisphere. Upon this use of water in commerce depends the distribution throughout temperate lands of such essentially tropical fruits as bananas and pineapples.

**Refrigeration**

## QUESTIONS

1. Write an account of the value of water to the manufacturing industries.
2. Name some uses of water in commerce.
3. In what way does irrigation reduce the risk of famine in congested areas?
4. What factors have been important in bringing about the modern renewal of interest in irrigation?
5. Where is irrigation practised on a large scale in Canada? Contrast the products of the two principal Canadian irrigation centres.
6. Why is the St. Lawrence River so valuable to Canada as a waterway?
7. Write an account of how the development of modern refrigeration has conferred great benefits on dwellers in the temperate regions.

## PART FOUR

## LIFE

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### CHAPTER XIX

### THE NATURE OF LIFE AND THE RELATION OF PLANTS AND ANIMALS

**The Nature of Life**

Man does not properly understand the real nature of life. Yet it is quite clear that all material things on the earth may be classified as either living or non-living. We have little difficulty in recognizing that a dog or a plant is alive, and that such things as a piece of stone or a lump of iron are not. This is so obvious that we rarely stop to consider what makes this difference between the living and non-living forms of matter. It will therefore greatly assist us to consider just what are the ways in which living things differ from others. A little consideration will show that living things (1) respire, (2) grow, (3) require food, (4) reproduce themselves, (5) can move of their own accord.

On the contrary, non-living things can do none of these things.

**Characteristics of Living Things**

Let us now take each of the characteristics of living things in turn, and see how they are displayed by both forms of life.

*All living things respire*—This has already been discussed rather fully under the topic of the relation of oxygen to plants and animals. Suffice it to recall here that both plants and animals respire, and that they both use this process for the production of energy and the assimilation of food.

*Living things grow*—This is one of the most important distinguishing features of life. All living things, be they plant or animal, grow. For a greater or lesser period of time, they are occupied in building themselves up from small beginnings into larger things by materials which they abstract from their food. Non-living things never do this. It would be

Fig. 92.—Redwood Trees
These giant trees are the largest and oldest living things on earth.

a most surprising thing to discover, for instance, that a small chair had grown into a larger one during some period when we were absent from a room.

*Living things require food*—This also furnishes a very definite means of distinguishing between the living and non-living. Everyone knows that if food is withheld from animals, they waste away and die. This is not so obvious in the case of plants, since these procure their food from the air and soil in a form quite different from that used by animals. Man, however, finds that unless he takes steps to replace the food abstracted from the soil by plants, the yield from his crops steadily lessens. Fertilizing the soil is really an act of feeding the plants.

*Living things reproduce themselves*—This characteristic of living things distinguishes them very sharply from non-living things. Many common observations show you that all living things come from other living things.

For example, plants grow from seeds that were produced on plants which grew in a previous season. Chicks hatch from eggs laid by a hen. Fishes come from eggs produced from the bodies of other fishes. But one never heard of a suite of dining-room chairs coming from a single dining-room chair purchased some time previously. That all life comes from life, is one of the great facts of nature.

The powers of reproduction possessed by many forms of life is astonishing. For instance, a single bacterium may, in the course of twenty-four hours, reproduce itself many millions of times. It is this astounding rate of multiplication of bacteria which makes many of them such dangerous enemies of man.

Insects also possess surprising powers of reproduction. Professor Strickland, of the University of Al-

berta, has shown that the female pale western cutworm moth lays, on an average, 300 eggs. Assuming that one-half of her progeny were female and were all able to produce their quota of eggs, the result would be 6,750,000 cutworms during the third year; and this family would be small compared with that descended from a female army cutworm moth, which lays 1,000 eggs during a season. Fortunately for us, however, so many insects are destroyed by their enemies, that the actual number of survivors is comparatively small.

Many plants display similar powers of multiplication. Thus, a single poppy produces thousands of seeds during a season. Many weeds owe their destructive effects to their powers of rapid reproduction.

*Living things can move of their own accord*—This is obviously true of animals in general. Nearly every animal has the power to move from place to place. Generally speaking, plants do not possess powers of locomotion. It is a principal characteristic of plants that they are rooted to the spot. Nevertheless, some plants are capable of slow locomotion.

But there are other forms of motion beside locomotion, or changing from place to place. For example, there is the power of changing direction of growth. Many plants display powers of motion which enable them to fold or unfold their leaves under certain conditions of light and heat. This power of self motion is never displayed by non-living things. For instance, no one ever heard of a stone moving from the sunlight into the shade.

To sum up, then, we may say that the distinguishing features of living things are:

1. Power of movement, growth and reproduction.
2. The necessity of respiration and food.

*Forms of life*—Notwithstanding the great variety of living things, there are only two forms of life in existence on the earth. They are *animal life* and *plant life*. All living things belong to either of these two forms of life.

**Distinction Between Plants and Animals**

Generally speaking, it is rather a simple thing to decide whether a living thing is an animal or a plant. No one would make the mistake of calling a maple tree an animal, or a horse a plant. Yet, among lowly forms of life, this distinction is not so apparent. For example, is a sponge a plant or an animal? What are yeasts, moulds and bacteria? It is very difficult to draw hard and fast rules that fit every case in nature. Therefore, we must try to arrive at a few general ideas about the plants and animals, and to realize that there is a border line where the distinction is not very sharply drawn.

It is usual to class as plants all those forms of life which are capable of absorbing their food in the fluid state, and which have no powers of locomotion. On the other hand, animals possess the power of taking their food in the solid state and converting it into a fluid state. They also possess powers of locomotion. Then again, plants and animals both respire, but plants are not nearly as active as animals, and do not respire so freely.

In general, we may say that plants differ from animals in four important ways:

1. In their method of feeding.
2. Plants are not so active as animals.
3. Plants do not respire as freely as animals.
4. Most plants can build up food from simpler materials and are storers of energy, whereas animals break down complex food and release energy.

**The Interdependence of Plants and Animals**

All living things, whether plant or animal, require carbon, hydrogen, oxygen, nitrogen, and a few minerals to build up their bodies, and to supply them with energy. Green plants can, with the aid of sunlight, obtain carbon from the carbon dioxide present in the air or water in which they live. They take their hydrogen from water and salts. Their oxygen they get directly from the air, whilst the required nitrogen is abstracted from simple mineral salts, like the nitrates present in the soil.

That is to say, green plants can build up complex living material from certain elements and the simpler compounds, but none of the animals can build up these simple materials into the elaborate compounds which they need to produce energy and body material. They therefore obtain their carbon by breaking down the sugars, starches and fats built up by the green plants. Their nitrogen requirements are furnished by the proteins. These are very complicated compounds containing nitrogen. Animals are therefore completely dependent upon green plants for their supplies of food and energy. Some animals obtain these essentials of life directly by eating green plants, while others get them indirectly by eating the flesh of the plant-feeding animals.

There are, however, many plants which are not green—for example, the fungi and bacteria. These are just as unable to build up food-stuffs from simple materials as are the animals. How, then, do these forms obtain their food? And how do they obtain the energy essential to life?

Most of the fungi are as dependent upon the work of the green plant as are the animals. They can live only where decay has provided them with food mater-

ials. Another type of fungus lives directly upon the sap of the living plant. Both types have already been discussed in Chapter XI.

Among *bacteria* there are forms which exhibit very remarkable methods of obtaining food and energy. Some can directly fix and use the nitrogen of the air, as was seen in Chapter XI. Others possess the power of abstracting their carbon from the carbon dioxide of the air without using chlorophyll. There is also another group which can live without the presence of free oxygen. This type is able to secure sufficient oxygen for its needs by abstracting it from compounds which contain it. But, after all, the great bulk of the living things of the world depend upon the manufacturing powers of green plants for their food and energy.

**The Cycle of Life**

The cycle of life is a recurring succession of processes in which all plants and animals are taking part. It may be outlined as follows. Green plants collect raw materials for food from the atmosphere and the soil. By utilizing the energy of sunlight they convert these simple food materials into more complicated ones called carbohydrates and vegetable fats and proteins. These are used by the plant partly for food and partly to build tissue. Plant-eating animals feed upon the plants and convert these vegetable foods into animal tissue. Other animals eat these plant-feeding animals. By the processes of life, death and decay of both plants and animals these complicated compounds are gradually disintegrated into the original simple materials and returned to the air and soil, and the plants collect them again. In this manner the proper balance of food and air on earth is maintained. Thus we see, that in a

very real sense indeed, plants and animals are dependent upon each other.

**The Struggle for Existence**

In the preceding paragraphs we have seen that, in the struggle for food and energy, living things are dependent upon each other. But the securing of food and energy is only part of the great problem of living. Living things wage a terrible warfare for room to exist, to obtain sunlight, to avoid extremes of temperature and to reproduce themselves. This ceaseless warfare among living things is called the *struggle for existence.* In the course of time the net result of the struggle for existence has been to produce a wonderful system of interdependence between plants and animals. This is what scientists mean when they speak of the *balance of life.*

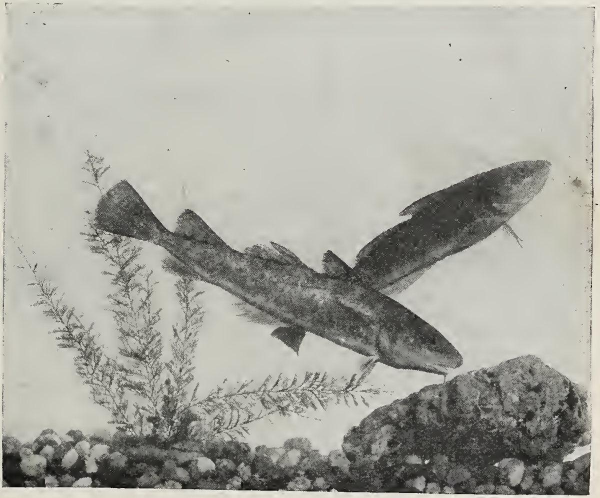
**The Balance of Life**

In any environment the conditions of sunlight, moisture and temperature produce a community of plants and animals, which live together in such a state of balance that each group is able to secure the necessities of life and reproduce itself. In such communities each group is dependent upon each of the other groups for its very existence. It is certain that any disturbance of the balance of life results in very serious effects on these communities.

The maintenance of the balance of life in the world demands that no large group of living things be detroyed; but on the other hand it must be held in check. There must be *some* insects, *some* birds, reptiles and worms, but not too many of one kind. In short, there must be the correct number of each kind of living thing for the maintenance of life as it is at present found on the earth. All the forces of nature are contributing to the maintenance of the balance of life.

**The Cycle of Life in the Water**

This interdependence of living things exists in the water just as it does upon the land. It begins with the plants which contain chlorophyll. These alone of all forms of life in the water have the power of capturing energy from the sunlight and building it up into complex food materials from simpler substances. Along the shores of seas and other bodies of water, sea weeds and algae grow in great abundance. By the aid of the energy of sunlight these species of plants build up food from carbon dioxide, water, and mineral matter containing nitrogen and some other elements. These plants form the food of small animals. The



*Courtesy N. Y. Zoological Society*

**Fig. 93.—Balanced Aquarium**
What do the fish supply to the green plants? What do the plants supply to the fish?

smaller animals and the young of larger animals are eaten by other larger aquatic animals. Thus, eventually, the food manufactured by the aquatic plants is built into the bones and muscles of the larger animals inhabiting the waters.

The waste products of these animals, e.g., the carbon dioxide from their respiration, and the excretion voided from their bodies, are returned to the waters. Here they are rebuilt into plants by the activities of the sea-weeds and algae, and thus used over again by the animals. Every living thing found in the waters is dependent upon some other living thing for its existence, and its survival results in the destruction of the particular form of life on which it feeds.

In order that plants and animals may carry on their struggle for existence more effectively, they modify themselves to suit their environment. This is called *adaptation to environment.* In the next two chapters we shall consider some of the most important adaptations of plants and animals to their environment.

## QUESTIONS

1. What are the characteristics of living things? Illustrate your answer by reference to (a) a plant, (b) an animal with which you are familiar.
2. Mention four important ways in which plants differ from animals.
3. How do we distinguish plants from animals among the lower forms of life?
4. How would you decide if a given substance were a living or a non-living thing?
5. How do green plants obtain raw material for food manufacture?
6. How do fungi and bacteria obtain their food?
7. Point out four ways in which plants and animals are dependent upon one another.
8. What do you understand by the term "struggle for existence"? Give an example.
9. What is meant by the term "balance of life"? Explain the principle of the balanced aquarium.

## CHAPTER XX

## PLANT LIFE

**Adaptations and Environment**

In the study of living things the term *adaptation* is properly applied to those special modifications of the living organism which arise as a result of its environment. *Environment* is understood to mean all the conditions upon which the life of the plant or animal depends.

There are seven principal factors which together make up the environment of all living things. These are food, light, air, soil, water, temperature, and shelter. Now, the success of any living thing depends very largely upon how perfectly it adapts itself to its environment. Let us see how plants meet the conditions of their environment.

**Adaptations to Obtain Plant Food From the Soil**

In Chapter XVI it was learned that one of the functions of the root system of a plant was the securing of water and food materials from the soil. At the same time we studied the manner in which these materials passed from the soil into the plant. If we make a collection of roots from various plants we shall notice:

1. That all of them have the same four fundamental divisions of main root, rootlets, root hairs, and root cap.

2. That the roots show many points of difference. For example, some of them will be fibrous, and others may be single, fleshy and spike-like in shape. We may

also notice that some are thick and woody. Again, others may be like small clusters of fleshy, potato-like growths. It is with these differences that we are now concerned, for they are all special modifications of the roots, for the purpose of securing food materials from the soil.

Some plants obtain their food from the upper layers of the soil. Such plants send out horizontal radiating roots, often for long distances from their stems, and near the surface of the ground.

Other groups of plants feed at a much deeper level in the soil. These send out a single tap-like root some distance into the ground. Plants of yet another class explore still lower layers of the soil in search of their food supplies. These deep-feeding plants send down long thread-like roots. Others, again, so modify their root systems that they are able to get their food materials in very wet soils. In every case we find that there is a corresponding change in the form of that root system to suit the conditions in which the plant must collect its water and food materials from the soil.

Again, the quantity of food available produces a modification in the size of the root. Soils poor in nutriment cause the roots to be sent much farther in all directions in search of food. Rich soils correspondingly cause root systems to cover a relatively smaller area. Stony soils produce crooked roots, and so on. Some plants, like the lichens, which grow upon rocks, secrete an acid that helps to dissolve the rocks and so enables the tiny plant to obtain the minerals necessary for its food.

The stomata of the leaves are organs whose special function is to collect plant food from the air. How they do this has been explained before in Chapter XI, when studying photosynthesis. But many plants

curiously modify their roots so that they may obtain plant food from the air through them. In fact some of these plants never send any roots into the soil at all. They gather all the raw material for their food from the air. Such plants are called *epiphytes* or *air plants.* The best-known of these plants are the tropical orchids. They grow perched on the branches of trees and their roots hang down in the air. Since they do not feed on the plant to which they cling and because they contain choloro-phyll, they are not parasitic, the perching habit being purely a device to gain an advantage of position in their struggle to get food. Those mosses and lichens which hang from the stems and branches of trees in temperate regions are examples of epiphytic plants.

**Adaptations to Obtain Plant Food from the Air**

Fig. 94.—Aerial Roots of an Orchid

Climatic conditions are usually understood to mean the average state of light, temperature, moisture and wind found in any given region. Since these vary

very greatly at different parts of the earth, it is to be expected that plants will be found peculiarly adapted to meet the conditions of life in the different regions. The plant needs light in certain quantities in order that it may carry out the important process of photosynthesis. In some parts of the world there

**Adaptations to Meet Climatic Conditions**

Fig. 95.—The Reach for Light of a Tree on the Edge of a Wood

is too much light. In such regions the plants meet the conditions by modifying the amount of foliage produced. Often they dispense with leaves altogether, using instead enlarged and modified stems, which carry the stomata and become heavily charged with chlorophyll. The changed stems thus assume the functions of leaves. This adaptation is characteristic of such regions as the hot sunny deserts. The cacti

are very excellent illustrations of how the plant meets excessively sunny and dry conditions.

Another way in which plants meet excessive light conditions is by producing a greyish hair-like growth on their leaves. The purpose of such growth is two-fold; it reflects a considerable portion of the light, and also bends a number of other light rays so that they do not reach the leaf itself. The common mullein is an example of this type of adaptation.

In shady regions, where the light is not so intense, the plant makes its leaves larger and lengthens the petiole or leaf stalk so as to raise the leaf out of the shade. It also produces leaves of varying sizes which rather neatly fill the open spaces left by the larger leaves.

Heat is necessary to a plant, but too high or too low a temperature is undesirable. Too high temperature conditions are met by many adaptations, e.g., increasing the rate of transpiration whenever moisture conditions render it possible. This tends to counteract the heat by rapid evaporation, much in the same way as the act of perspiration makes us cooler on hot days. To meet cold temperature conditions, plants often cover their stems and leaves with a growth of hair. The common so-called "crocus" of the prairies affords a good example of this type of adaptation.

Clustering the leaves in a rather tight rosette, flat or nearly flat on the ground, is a device used by many plants to resist either intense light or cold, or drought. Moisture may be excessive in some localities. The plants inhabiting such places show several interesting adaptations. Curtailing the area of the root system is a common device, since it reduces the amount of water taken into the plant. Enlarging the leaves, producing larger numbers of them, and de-

veloping stomata on both sides of the leaf are other devices, since these all enable the plant to pass off larger quantities of water by transpiration. Excessive rainfall is often met by the development of a waxy substance in the skin of the leaves and by hairy growths. The leaves are often changed in shape under these conditions, the most favoured being a long and narrow leaf with sharp points and indentations on the upper surface. These indentations form channels down which the excess moisture drains rapidly off the leaf.

Scarcity of moisture is combated by reducing the size and number of the leaves, thickening the leaf and stem, and developing large water-holding cells or spaces in these parts.

Plants are often liable to damage by high winds. The trunks and limbs of trees are subject to immense strain in a high wind. The central part of the stem or heart wood is very strong and acts like a reinforcing rod. The limbs are, for the most part, slender and remarkable for their elasticity. Many stems are hollow, so that they have great powers of resistance for their weight. Some trees are strengthened by thickening, by buttress-like growths, and by prop roots at places of greatest strain, viz., at the base of the trunk.

The leaves of trees growing in regions subject to high winds are usually either small or else very much compounded, and are attached to the branches by slender and elastic stalks. The resistance they offer to the wind is thereby reduced. The whole general construction of plants is an adaptation against damage from winds.

In the temperate zones of the world the succession of four seasons requires special adaptations on the part of plant life. These adaptations are accomplished in four principal ways:

**Adaptations to Meet Seasonal Changes**

1. Some plants (called annuals) die off each year, but during the single year of their life produce a great number of seeds, which lie dormant in the ground until the spring of the following year. They then germinate and repeat the process. Thus their kind is maintained on the earth.

2. The characteristic trees and shrubs of these zones shed their leaves in the fall, withdraw the sap into the root systems and remain dormant throughout the winter season. In the spring the sap rises, new leaves appear, and the plant resumes its active life until the fall season of the year.

3. Some plants adopt what is called the *biennial habit.* That is, they spend one spring and summer season actively engaged in manufacturing an excess of food, converting it into starch and storing it in their roots, tubers and stems. They then die down and, during the next season, grow up again. During this second period they work mainly towards the business of producing seed, their food manufacturing activities being kept down to the minimum because they can draw upon the stored-up food to provide the energy they require. Carrots and turnips furnish examples of this seasonal adaptation.

4. Others have adapted themselves to the *perennial habit.* That is, they die down each fall, remain dormant all winter and obtain an early start in the spring, by drawing upon food stored in their roots for this purpose during the summer of the previous year. Many common garden plants do this, e.g., the iris, peony, phlox, delphinium.

All animals depend, directly or indirectly, upon plants for their food supplies. The feeding habits of

some animals cause great damage to plant life. In many cases, however, the animal secures its food without seriously damaging the plant life of a region.

**Protection Against Animals**

Browsing on the lower branches of trees or pasturing on the grasses does not usually cause serious injury to the plants. If, however, the animals which feed by these methods become too numerous in proportion to the luxuriance of the vegetation, they may inflict heavy damage. Fruit - eating animals may even be beneficial to the plant by dispersing its seeds or assisting in the act of pollination. But the seed - eating animals and those which, like the hog, dig up fleshy roots, bulbs or tubers for their food, cause great harm to the plants of a region.

*From Gager's Fundamentals of Botany*

**Fig. 96.—Venus's Flytrap**

When insects alight on the leaves, the halves quickly close, and the teeth on the edges interlock. The captured insect is then digested by the ferments secreted from the leaf surface by certain cells in this part of each leaf.

Wood-boring insects, sap-drinking birds and insects, as well as snails, are very destructive to plants. Gnawing animals also do great harm to plant life by ringing the bark, while burrowing animals and cutworms cause damage by destroying the underground part of the plant.

*From Gager's Fundamentals of Botany*

Fig. 97.—Sundew

Note the sticky hairs (tentacles) on the margins of the leaves. The insects that alight on the leaves are caught by these tentacles which bend over the insect and pour out a protein-digesting enzyme.

Many protective adaptations against these attacks are to be seen. The principal are:

1. Keeping a bodyguard of ants. Most ants feed upon insect life. It has been estimated that ants of a single nest may destroy 100,000 insects in one day. In the Province of Canton in China, the orange growers place nests of ants in their orange trees, and connect the trees with bamboo poles to form bridges by which the ants may travel from tree to tree. More than 3,000 species of plants produce special food to

attract ants. The ants repay this service by keeping such plants clear of insects.

2. Mimicking the appearance of dangerous and uneatable plants, or imitating pebbles or earth so that they may be overlooked by animals in search of food. Many instances of this are to be observed in the dry belt in Southern Alberta, where conditions of life for plants are very severe. For example, one of the wild mints resembles the stinging nettle. Many cacti grow in tight masses that resemble a stone, and some white plants grow in patches resembling lichens.

3. Arming exposed parts with cutting edges, sharp or stinging hair, prickles, or thorns, e.g., the sword grass, mesquite, thistle, stinging nettles and roses.

4. Producing tough, woody, or flinty tissues which make the plant uneatable, e.g., lamb's quarter, cottonwood bark, rushes, knot grass, and the scouring rush (equisetum).

5. Accumulating unpleasant or poisonous juices in their stems and leaves, e.g., maple twigs, tansy, wormwood, horse-radish, onion, wild parsnip and dandelions.

6. Growing rosettes flat on the ground, e.g., shepherd's purse and common plantain.

7. Producing seeds enclosed in horny or hard fibrous cases, or covered with an oily coating. Such devices protect the seeds from the digestive juices of birds and animals, thus enabling them to be spread by the fruit-eating animals.

In their struggle to adapt themselves to their surroundings, plants labour under one very great disadvantage. They have no powers of locomotion and are consequently unable to move from an unfavourable locality to one more suited to their requirements. This handicap seriously reduces the power of the plant to meet changing conditions. In consequence, any mater-

ial change in the environment causes great loss to the plant life of the place.

## QUESTIONS

1. What does adaptation to environment mean?
2. What special modifications are made in the plant body to enable it to obtain food materials (a) from the air, (b) from the soil?
3. Name, giving examples, adaptations in the forms of the plant body (a) to meet changes in the seasons, (b) for protection against enemies, (c) to ensure a scattering of seeds.
4. Name four distinct conditions to which plants must adapt themselves in order to live.
5. Name and show the fitness of six special adaptations in the body forms of plants which assist them in their struggle for existence.
6. Name four special adaptations made by plants in order that they may live successfully under special climatic conditions. Give an example of each.
7. Name two distinguishing characteristics each of plants growing in (a) a shady location, (b) water, (c) a very dry and sunny location.
8. How are ants of use in protecting plants against damage by insects? Give an instance of ants being used by man to protect his crops.
9. Under what serious disadvantages do plants labour in their struggle for existence? What is the practical result of this condition?

## CHAPTER XXI

# PROCESSES BY WHICH PLANT FOOD IS TRANSFORMED INTO RESERVE FOOD AND STORED IN THE PLANT

In the study of photosynthesis in Chapter XI, it was learned that plants manufacture their food from carbon dioxide and water. The first product of this food-making by plants is sugar. Sugar is soluble in water, and therefore can be used immediately by the plant for food. But the plant only makes sugar during the hours of sunlight and, in the temperate zones, only within certain seasons of the year. During these periods the plant manufactures more sugar than is needed for immediate use. It changes the excess into a form in which it may be stored somewhere in the plant body for future use.

Again, sugar is not the only form of food required by the plant. It must have fats and protein also. By some means not yet well understood, plants are able to change the sugar manufactured by photosynthesis into fats and proteins. Neither of these compounds is soluble in water. It is certain, however, that the plant can send sugar in the form of sap to certain places in its tissues. The transfer of sap is accomplished through the elaborate system of tubes and cells already described in Chapter XVI. On arrival at these points it is changed into starch, cellulose, fat or protein, as the plant requirements demand. When so converted, it is stored in cells until

**Conversion and Storage of Food**

required. Many common forms of storage of reserve food are easily noted, e.g.,

*In seeds*—Starch storage may be observed in peas, beans, wheat, barley and rice.

Oil storage in the seeds of the flax plant, peanuts, Brazil nuts, walnuts, cocoa beans and cocoanuts.

Cellulose used by the plant to build cell walls is stored in the seeds of dates.

Proteins are stored in oats, wheat and beans.

*In stems*—Starch is stored in the soft cells of the wood of trees and shrubs, e.g., sago in the trunk of the sago palm.

Starch is also stored in tubers as in the potato and the artichoke.

Sugar is stored in the stem of the sugar cane.

*In roots*—Starch and oil are stored by many perennial plants in their roots. This is true of rhubarb, the dahlia and the peony.

Sugar is stored in the roots of the beet and the carrot.

Experiment 58.—*To show the presence of starch, fats, and proteins stored in the roots, stems, and seeds of plants.*

*Required:* Beans, walnuts, potatoes, celery, carrots, tincture of iodine, nitric acid, and ammonia.

*Procedure:* Expose an inner surface of each material by cracking or peeling, and apply a drop of tincture of iodine to each. A blue colour indicates the presence of starch. Next, to a fresh lot of material similarly prepared, apply a drop of concentrated nitric acid. A yellow colour shows the presence of protein. This yellow colour will change to orange if moistened with ammonia. The presence of oil or fat in the walnut may be shown by wrapping up some kernels in soft paper and pounding for a time. On opening the mass, grease stains will be observed on the paper.

*Conclusion:* Since beans and walnuts are seeds, potatoes and celery are stems, and carrots are roots, these simple experiments show that starches, fats, and proteins may be stored in the roots, stems, and seeds of plants.

*How the plant food is transformed into plant tissue*

—This is accomplished by the plant digesting and assimilating its food.

**Digestion by Ferment**

Digestion is the conversion of insoluble plant food like carbohydrates, fats, and proteins into soluble substances, and dissolving them. This conversion and solution is brought about by certain ferments produced by particular cells of the plant. There are several of these ferments present in all plants. One of the best known is called *Diastase*. It changes starch back into sugar, which can then be used by the plant to provide energy. Another set of ferments called *Lipases* acts upon the fats, and yet another group acts upon the proteins and is known as *Proteoses*. All such ferments used by plants and animals to digest their food are known as *Enzymes*. After the food has been digested it is still not part of the living plant; another process has yet to take place. The digested food must be built up into, and made part of, the living tissues of the plant. It must be transformed from the lifeless matter into living matter. This is what is known as assimilation. Just how digested food is assimilated is not understood. All that is clear is that only the action of living things can convert the non-living into living material. In some mysterious way, then, digested food is taken by each separate cell in the living plant and built up into new cells to provide for growth, to replace those worn out, and to form the seeds for the next generation.

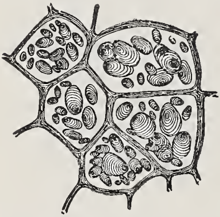


Fig. 98.—Starch Grains in Cells of a Potato

**Experiment 59.**—*To show that the enzyme, diastase, can change starch into sugar.*

*Required:* Barley kernels, test tubes, 1% starch solution, Fehling's solution No. 1 and 2, filter paper and glass funnel, flask, mortar and pestle, spirit lamp.

*Procedure:* Crush about 20 barley kernels in the mortar, transfer to a test tube and add 15 c.c. of water. Let stand for 24 hours and filter off the solution. Put about 100 c.c. of the starch solution in the flask and add the filtered liquid from the crushed barley kernels. Leave for another 24 hours and test with the Fehling's solution.

To do this, filter about 10 c.c. in a test tube and add about half as much Fehling's solution No. 1. Next add sufficient No. 2 Fehling's solution to produce a deep blue, clear liquid. Gently warm this liquid. The appearance of brick-red streaks shows the presence of a simple sugar. Try the effect of Fehling's solution on some of the starch solution that has not been treated with the barley extract. No change of the blue colour will be observed.

*Conclusion:* Barley kernels contain the ferment diastase which can be extracted with water. This barley extract changes starch into a simple sugar. It is an enzyme produced by plants and used by them in digestion.

## QUESTIONS

1. What are the processes by which plant food material is changed into plant food and tissues? Point out the essential differences between them.
2. In what parts and in what form do plants store their surplus food supplies?
3. What is an enzyme? Name three enzymes found in plant bodies and tell what class of foodstuffs each acts upon.
4. Describe experiments by which you might show the presence of (a) starch, (b) fats, (c) proteins stored in various parts of a plant.
5. Describe how you might extract diastase from barley seeds, and then demonstrate that it can change starch into sugar.

## CHAPTER XXII

# PRODUCTION AND DISSEMINATION OF SEEDS

The ultimate aim of all plants is the production of young plants in order that the species may continue. Plants reproduce themselves in many ways. Some, like the yeasts, accomplish this end by simple division of the cells, which in turn repeat the process. Others, like the moulds and ferns, produce spores. The most common and best-known method, however, is by the production of seed. Some of the seed-bearing plants possess in addition powers of producing new individuals direct from buds on runners, roots and leaves. The direct method of reproduction without seeds is called *vegetative reproduction.* It may be noticed in many well-known plants, e.g., strawberry, white poplar, Canadian water-weed and couch grass.

**Plant Reproduction**

Only the flowering plants produce seeds, the flower being the special adaptation of such plants for this purpose. The parts of a flower necessary for the production of seeds are the *Stamens* and the *Pistil.* These are, therefore, known as the essential organs. Many flowers possess other parts which assist the essential organs in many ways. These accessory parts are called the *Floral Envelope.* This floral envelope, when complete, consists of a calyx and corolla. The chief function of the calyx is to protect the essential organs against cold and the ravages of insects. The principal work of the corolla is to attract various kinds of animal life upon which the plant depends for pollination.

This is brought about by the development of showy colours, attractive perfume, and the secretion of nectar in the petals of the corolla. Often the corolla assumes the role of protection by growing in peculiar shapes, which prevents undesired visitors from removing the pollen at unsuitable times.

**Complete and Incomplete Flowers**

When a flower possesses all the essential organs, together with the floral envelope, it is called a *complete flower.* Many flowers have one or several of the parts missing; they are then termed *incomplete flowers.* There are several flowers in which either the pistil or the stamens are lacking. Such flowers are called *pistillate* when the stamens are absent and *staminate* when the pistil is not present. Some plants bear separate pistillate and staminate flowers on the one individual growth, whilst others produce the pistillate flower on one individual, and the staminate flowers on another.

Cucumber, corn, hazel, pine and pumpkin are plants which produce both types of flowers on the same plant. Willow, poplars and Manitoba maple are plants which bear the staminate flowers on one tree and the pistillate flowers on another.


**Fig. 99.—Catkins of a Willow** A staminate flower is shown at *s*, and a pistillate flower at *p*. The staminate and pistillate are on different plants.

Before seeds can be produced, pollen from the stamens must be transferred into the pistil. This process is called *pollination.* How it is effected will now be explained.

Pollen is a dry, fine, granular powder contained in the little receptacles on the tops of the stamens of the flower. It is most often yellow in colour, although other colours are not uncommon. (See Fig. 101.)

An examination of the pistil of a flower will reveal three distinct parts: a flattened or knob-like top and a swollen part at its base, these being connected by a narrow neck-like tube. Inside the swollen base are a number of chambers containing minute bodies called *ovules*. The flattened top is called the *stigma*, the neck-like tube is known as the *style*, and the swollen base is the *ovary*. The chambers are called *capsules*.

At the proper time the stigma becomes coated with a sticky substance. The pollen grains falling upon it, when in this condition, are retained on its surface.

**Pollination**

These grains then send fine tube-like extensions down the style, which finally bursts, discharging the contents of the extensions into the ovary. These unite with the ovules and pollination is complete. Soon the stigma and the style die. The ovary grows larger and larger until finally its capsules are filled with seeds.

This act of pollination is essential to the production of seed. There are two modes by which it is accomplished:

1. *Self-pollination*—In this method the pollen is transferred from the stamens to the stigma of the same flower.

2. *Cross-pollination*—Here the stigma receives the pollen from the stamens of another plant of the same kind.

Cross-pollination is the better method of the two, for it results in hardier and better quality seeds and larger crops than are produced by self-pollination. Plants have many interesting adaptations for securing

cross-pollination, and use various agents to transfer the pollen grains from one individual to another.

*Adaptations for preventing self-pollination*—

1. Producing staminate and pistillate flowers on different individuals.

2. Ripening the pollen and the ovules at different times, but producing both stamens and pistil in the same flower.

3. Arranging the flower parts so that it is very difficult for the pollen to reach the stigma of the same

*Courtesy Dr. Frederick V. Coville*

Fig. 100
Result of Self-pollination (left), and Cross-pollination (right) in Blueberries

flower. This is well illustrated by the Lady's Slipper Orchid.

4. Having such pollen grains as will not produce any effect on the ovules of the same flower. This is the case in the corn plant.

*Adaptations for securing cross-pollination*—To secure cross-pollination the plant makes use of the wind, water, insects and birds to carry pollen from one plant to another.

*Wind-pollination*—The plants adopting this method produce great quantities of pollen, since much of it is wasted. Their flowers usually have special modifications of the stigma, so that they may present large areas to the wind, and are usually lacking in bright colours or attractive perfume. The flowers often hang in long clusters called catkins. The grasses, hazels, and poplars are representatives of wind-pollinated plants.

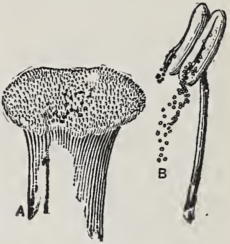


Fig. 101.—*A*, pollen germinating on a stigma. *B*, pollen escaping from anther. Enlarged.

*Water-pollination*—This is a method adopted by plants which live almost entirely under water. The pistillate flowers are usually attached to long slender stalks and float on the surface of the water. The staminate flowers, when ripe, break away from their submerged stems and float to the surface. The pistils catch and retain some of the pollen from the staminate flowers, as they pass under the pistillate flowers. After pollination the stalk of the pistillate flower coils up and draws the flower below the water again. Eel grass is pollinated in this manner.

*Insect-pollination*—One of the commonest plans is to

attract bees, and during their visit dust with pollen. When they fly to another flower some of the pollen dust is rubbed off on the sticky stigma. All flowers using this method secrete nectar which the bees collect and convert into honey. Some attract moths, others are attractive to butterflies, yet others to midges or gnats. In most cases insect-pollinated flowers are brightly coloured so that they are easily found by insects. Those which depend upon moths to transfer pollen are characterized by the exudation of heavy perfume at dusk and by the white, creamy, yellow, pale blue or pink shades of their petals. This is an adaptation to the habit which moths have of flying in the evenings. In addition all insect-pollinated flowers produce nectar on which the insect feeds and for which it really visits the flowers.

*Bird-pollination*—Some flowers with very long tubular corollas depend entirely on birds for cross-pollination. The gladiolus, salvia and trumpet-honeysuckle are examples of such plants. The humming birds with their powers of hovering and long bills are peculiarly adapted for this service.

After the plant has produced and ripened its seeds it must distribute them as widely as possible. This distribution or dissemination of seeds is necessary for two main reasons:

**How Seeds are Disseminated**

1. To spread the species.
2. To prevent overcrowding.

Many special devices are found amongst plants which enable them to disperse their seeds in a very effective manner. Some plants spread their seeds by exploding the seed-pod or capsule and violently expelling the seeds to a distance. Peas, carragana, and the squirting-cucumber are plants which use

this sort of device. It is, however, not very effective, since the distance obtained is never very great. A much better effect is obtained when the plant uses some outside agent to transport its seeds. The principal agents used are wind, water, gravity, animals and man.

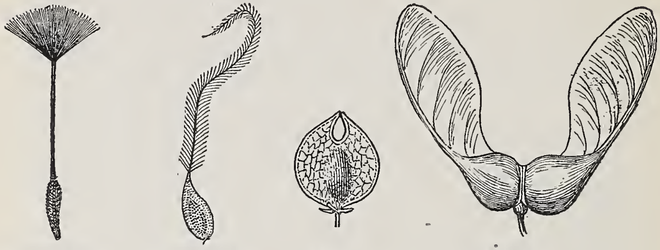



**Fig. 102.—Fruits and Seeds Dispersed by Wind**

*Wind dispersal*—This agent is utilized by means of several interesting adaptations. In some cases the seeds are very small and light, and are easily blown from the plants and carried quite long distances away. Other seeds are tufted or plumed and are wafted considerable distances by the currents always present in the atmosphere. The dandelion, milk-weed, fire-weed, and the thistle furnish examples of this method. The maples produce seed with wing-like structures attached to them, which buoy them up, thus enabling them to sail away from the parent plant. Some plants, like the tumbling-mustard and the tumble-weed, break off just below the crown. This produces a more or less round and light ball which may be driven long distances before the wind, shedding the seeds as it travels.

*Dispersal by animals*—Birds and other animals eat the fruit enveloping the seeds of many plants. When

such fruits are eaten the softer parts are digested, but the seeds, protected by horny or tough indigestible coverings, pass through the digestive tract unharmed and are thus carried long distances away.


Fig. 103.—Explosion of the Balsam Pod

Again, many seed capsules are provided with hooks or spines, with which they cling to the coats of animals and are thus carried to new ground. Burdock, buttercups and wild carrot seeds are dispersed in this manner. Some seeds are transported by clinging to the mud on the feet of birds and animals, and so may be carried very long distances.

*Dispersal by man*—This may be accomplished by accident; for example, by seeds clinging to a man's clothing or shoes, or by their presence in dirty seed grain. It may also be done deliberately, as, for example, when a farmer or a gardener plants some variety of crop or flower or tree that he has imported.


Fig. 104.—Stealing a Ride

A great many of our most troublesome weeds have been either accidentally or designedly transported by man, and, because there are no natural

checks on their increase, have multiplied so rapidly as to become a nuisance.

*Dispersal by gravity*—Round seeds roll away from the plant down the leaves and down the slopes of the ground.

*Dispersal by water*—Many seeds fall upon the water and, because they are able to float, they may be transported long distances by streams and waves. Cocoanuts, for instance, are transported by the waves and currents of the ocean between islands of the tropical seas.

## QUESTIONS

1. What is meant by vegetative reproduction? Give some examples from ordinary garden practice.
2. What is a flower? Make a sketch of some flower that you know and indicate on it the essential organs.
3. Suggest possible reasons for (a) the presence of nectar in a flower; (b) the bright-coloured petals of certain flowers; (c) the pale shades and heavy perfume of such flowers as the evening primrose; (d) lack of conspicuous or brightly coloured flowers on grasses.
4. Distinguish between (a) complete and incomplete flowers, (b) staminate and pistillate flowers.
5. What is pollination? How is it accomplished by the plant?
6. Mention some adaptations of plants for (a) preventing cross-pollination, (b) securing cross-pollination.
7. What is a seed? By what various means is the dissemination of seeds accomplished? Give an example of each to be found among the plants of the Province.

## CHAPTER XXIII

## PLANT DISTRIBUTION

Every area of the land on the globe supports a more or less dense plant population. Examine the so-called

**Universal Distribution of Plant Life**

bare rocks and, here and there, tiny plants called mosses and lichens will be found growing upon them. Even the ice-covered interior of Greenland and Antarctica are not, as is often thought, entirely without plant life. Travellers in these regions have told us that the snow is frequently coloured red. This "red snow", as it is often called, is really a tiny alga growing so thickly on the snow as to make it appear red. Contrary to popular belief even the great deserts of the world show an astonishing abundance of plant life.

It is the same with the waters of the earth. The oceans and inland waters support an abundance of vegetation strangely modified to suit the conditions under which it exists.

If we turn to the atmosphere we find that it also is the home of countless plants which we know as yeasts, moulds, and bacteria.

The shallow seas which fringe the shores of the great land masses support the most dense plant popu-

**Marine Plants**

lations of the seas. This is because the conditions of light, temperature and food supply are most favourable there. The rocks and silt also contribute to this greater density of plants in these areas, by providing

material in which the roots of the aquatic plants may anchor themselves.

In the more open and deeper parts of the oceans most of the plants are free-floating. That is to say, they are not attached by roots or other devices to the floor of the ocean, but are carried about by the convection currents in the waters. Upon this mass of vegetation the whole of the animal life of the seas depends. Much of the free-floating plant life of the seas is microscopic in size, as for example, the diatoms. A large proportion consists of plankton and algae. Such forms of plant life are the principal sources of the food supply of many fishes. They are especially abundant in the waters over the continental shelves. It is the concentration of such enormous numbers of these free-floating forms of plant life in the shallow seas off the Pacific coast of Canada, the Banks of Newfoundland, and in the North Sea that makes these regions such valuable commercial fishing grounds.

**Fig. 105.—Fucus or Brown Seaweed**

Among the anchored forms of sea plants we notice the sea-weeds. The name sea-weed is the popular name for a great variety of marine plants, the chief of which are kelps, rock-weed, and sargassum-weed. These plants are all attached in some way to the rocks and silt lying at the bottom or along the shores of the sea. They are all beautifully adapted for floating on the surface of the water, some by the development of bladder-like vessels filled with air, while others as-

sume a flattened form of leaf and stem which spreads their weight over a greater area of water. This flattening is a great aid to them in floating.

**Fresh Water Plants**

Any slough or lake near your home will afford you plenty of material for the study of fresh-water plant life. Notice here that the water plants are most numerous near the edges of the water. How do you account for this? Again we see how the majority of the true water plants near the edges are growing from the mud at the bottom of the pond, or else are attached to submerged logs or stones lying at the bottom of the slough.

**Fig. 106.—Nitella, a Fresh-water Weed**

Further out in the water will be seen masses of green slime, which when taken from the water are seen to be composed of long, slender, green threads. These are not attached to the bottom. They are a form of alga. Beyond these may be seen tiny disc-like plants, often showing pretty little white flowers. These are also free-floating. If some are collected, tiny little bladders may be found attached to the little plant by thread-like stems. What is the purpose of these bladders? Sometimes these bladders may be found within the leaves themselves.

At certain times of the year the slough may contain pond lilies. Notice the long stem. Try to pull it out of the water. It will be found attached to the bottom. Look, now, at the leaves of the pond lilies. How large they are! How easily they float on the water! Why make it possible for such a large object to float

on the surface? Lift a leaf from the water. Does it keep its shape well? Examine it carefully and compare it with a large leaf from some land plant. Notice that the pond lily leaf has no stiffening ribs like the land plant leaf.

Can you suggest a reason? Put the lily leaf back into the water. Does it spread out well? What is the use of the ribs on the land plant leaf? What accomplishes the same object for the water lily leaf? Do you think the absence of ribs in the leaf of a water plant is an adaptation to environment?

Many of the plants will be seen to be completely submerged. That is, the roots, stems, and leaves are entirely under water. Find some of these. Notice how the leaves are now no longer large and spread out flat, nor are they so vivid a green in colour. They are long and narrow. Often they are ribbon-like in form and in some plants so subdivided that they look almost like threads. How do you account for the change in colour? (Consider how much sunlight can reach them under water.) What reasons can you give for the cutting up of their leaves into ribbons or thread-like shapes?

Some pond weeds will be seen to possess both submerged and floating leaves. Are both sorts of leaves the same shape and size? What about their colour? Do both kinds of leaves grow on the same plant?

Farther out in the pond there is a great abundance of microscopic forms of plant life. If your school possesses a compound microscope, collect some of these by means of a silk bag stretched over a wire frame and examine them under the microscope. Such an examination will reveal to you a new world of beautiful objects. From our study of the plant life in the waters of a pond, we see that aquatic plants possess many adaptations of form and organs which enable them to

get their food materials, capture light energy, and obtain support and anchorage in the waters of the earth.

**Land Plants**

The most outstanding feature of the land plants is their habit of banding together in certain well organized groups. Everyone is familiar with some one or other of these groups, to be found on grassy plains, woods, swamps and marshes, and around the margin of ponds and streams. It is this habit of grouping by plants that gives variety and charm to the landscape. Since one of the functions of science is to find out causes, let us see if we can discover any reasons for the formation of these groups.

We have already learned that plants need certain conditions of sunlight, temperature, moisture and soil in order to live. Now for each plant there is a certain combination of these conditions which is the most favourable to its mode of life. Every plant is engaged in a struggle to obtain the necessities of life. The many different conditions of light and shade, moisture and dryness, fertility and poverty of the soil, heat and cold, are all operating to alter the character of the plant life in different localities. This results in many modifications of form among plants so that they may each obtain the sunlight, heat, moisture, food, and air necessary to their existence on the earth. In other words during the long course of time they have become adapted to their different environments.

**Plant Societies**

This struggle for the necessities of life has resulted in many different forms of plants living together. They are able to do this because they require varying amounts and kinds of food materials, different degrees of temperature, greater or less intensity of sunlight,

greater or less amounts of air. For this reason groups of widely dissimilar plants come to live together in communities. Such groupings are called plant societies or plant associations. There are many kinds of such societies, and many ways of classifying them. But one of the most useful is that which is based upon the moisture supply, since all plants are greatly dependent for life upon the proper supply of water. This way of looking at plant societies gives us three main types of plant groups:

1. *Wet region societies*, e.g., swamps, jungles.
2. *Arid region societies*, e.g., deserts.
3. *Mid-region societies.* This is a mixed type of vegetation and is by far the most common type.

*Forest associations* are groupings of many different types of plants, from tall woody trees, down through shrubs, bracken and fern, to the smaller flowering plants growing thickly between them. For their formation abundant supplies of water and plant food

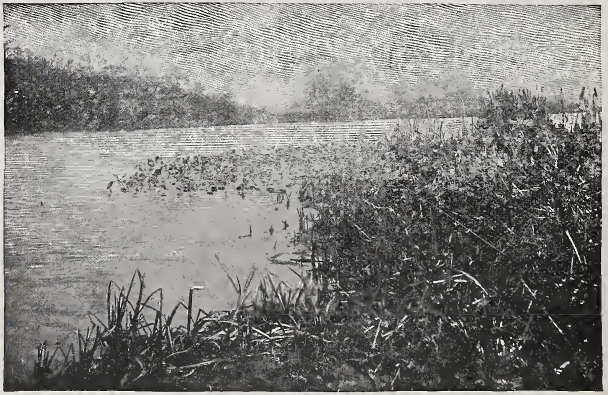


**Fig. 107.—A Wet-Region Society**

(humus) in the soil are the chief requisites. There are temperate region forests with characteristic coniferous trees with needle-like leaves, and the deciduous trees such as poplar, birch, and elm. In the tropics we find another kind of forest which is characterized by broad-leaved evergreen trees, creepers, vines, and rank luxuriance of vegetation due to the excessive moisture and high temperature conditions.

*Jungles* are the product of poor drainage conditions in the soil together with high temperature and soils rich in humus. They are characterized by rankness of growth and the presence of reed-like grasses and bamboos. They are especially found in the monsoon regions of the world.

*Swamp associations* are associations of water-loving plants like mosses, woody shrubs, and reeds. They are largely due to poor drainage and low or medium temperature conditions. Sometimes forest trees like tamarack and cypress are found growing within them.

**Fig. 108.—A Mid-region Society**

Such associations are called forest swamps. There are several other types of swamps, as, for example, reed swamps, peat bogs, or muskegs. Their names are given to them from the characteristic type of plant which grows there.

*Grassy plain associations* are the result of semi-aridity and rich soils, together with a rather flat or rolling surface to the land. The characteristic vegetation is grasses and herbaceous plants with low shrubs, and interspersed bluffs of willow thickets and trees such as the aspen.

*Tundra associations* are due to poor drainage caused by the more or less permanently frozen subsoil and short hot summer season. They are characteristic of high latitudes. The vegetation is abundant, and they are noted for their great variety of flowering plants and low-growing woody shrubs.

*Desert associations* are primarily due to lack of moisture. They are especially characteristic of the Trade Wind regions of the world. The state of fertility of the soil has little to do with the formation of a desert. The plant life of these arid regions is fantastic. The struggle for life is intense and many strange adaptations are to be seen in plants living in deserts.

Undoubtedly the best way to study plant associations is to visit the different societies which can be seen in the vicinity of the home or school. Far more can be discovered in a few hours' study of actual plant groups on the spot than can be acquired by months of reading. Look around you and make your own observations, then try to explain what you see.

The study of the relations of plants to each other and to animals is called *Ecology*. It is one of the most fascinating branches of science.

## QUESTIONS

1. What are free floating forms of plant life? Where are they usually found? What types of these plants are found (a) in the seas, (b) in sloughs and lakes?

2. What factors controlling plant life and its distribution may be shown to account for the valuable sea fisheries of the Pacific and Atlantic coasts of Canada?

3. Name four devices, or adaptations, used by water plants to hold their leaves at or near the surface of the water.

4. What are plant societies? How may they be classified? What are two main factors in the determination of the character of a plant society?

5. What conditions are most important in the formation of the following plant associations: (a) tundras, (b) jungles, (c) grassy plains, (d) deserts?

6. Distinguish between the conditions necessary for the formation of tropical and temperate forests.

7. What is Ecology?

## CHAPTER XXIV

## ANIMAL ADAPTATIONS

Just as plants adapt themselves for various reasons connected with their business of living, so animals are beautifully adapted by many changes of their form, colour, and organs to assist them in their struggle to live. The complete study of animal adaptations would require much more time and space than we can give.

We shall therefore consider a few typical adaptations of animals for securing food, for locomotion, and for protection.

**Adaptations for Securing Food**

All animals must secure food in order to live. They cannot under any circumstances manufacture their own food from simple materials. Some of them subsist entirely on plant food. Such animals are called *herbivorous*. Others are not fitted to eat plant food, but feed upon other animals. These are *carnivorous* animals. They depend upon herbivorous animals to convert the plant food into the flesh on which they feed.

Let us now consider the adaptations of plant-eating animals for obtaining food. In doing so we shall restrict the study to insects, birds, and mammals.

*Insects*—Those insects which live on plant food either bite the leaf or underground stem, or else bore through the bark and drink the sap. The grasshopper furnishes a convenient example of a leaf-eating insect.

The mouth parts of a grasshopper are concealed by an overhanging flap. If this be raised, the true

jaws can be seen. They consist of two mandibles with jagged edges arranged so that they open and close like pincers. Their action is somewhat scissor-like, and their function is to bite the leaf. Below the mandibles is a pair of soft jaws which assist in manipulating the food. Attached to each of the soft jaws is a

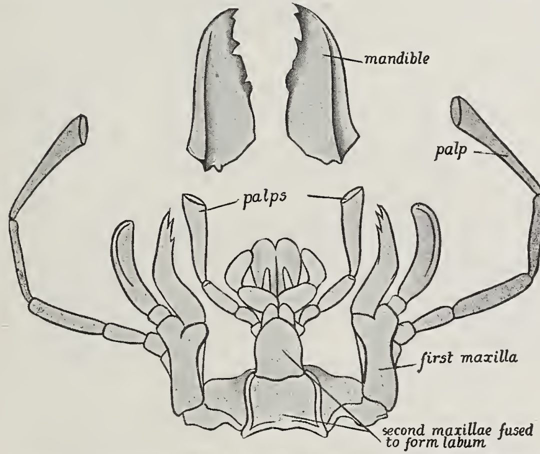



**Fig. 109.—Mouth-parts of Grasshopper (much enlarged)**

jointed structure called a *palp,* which is used to hold the food. The mouths of grasshoppers are very efficient tools, and the insect is extremely voracious. Grasshoppers do enormous damage to crops if they become too numerous.

*Insects which pierce the bark and suck the sap*—Aphids are typical insects feeding in this manner. They are small, green, oval insects, popularly called plant lice. The special adaptation which enables them to obtain their food is the mouth, which is formed like a tube or beak which can be forced through the bark

of trees, piercing the sap cells of the cambium layer, and sucking up their contents.

*Insects which feed on underground stems*—Cutworms are not true worms. They are the larvae of a moth. The name was given to them because of their resemblance to worms and because of their habit of eating through tender underground shoots of young plants. Jaws that can cut are the adaptation of cutworms for obtaining food.

**Insects as Destroyers**

The destruction wrought among both wild and cultivated plants by insects represented by the three types just considered is enormous. The grain destroyed by grasshoppers and other members of the locust family every year is very extensive. Fortunately, they are usually kept under control by parasites. Sometimes, however, it happens that during a certain season the parasites are not numerous enough to hold the grasshoppers in check. Then the balance of nature is disturbed, and we have a plague of grasshoppers, to the great loss of the farmer. Once they have got out of control, it takes several seasons before the grasshoppers are checked back to normal numbers again.

Aphids are particularly troublesome to house and hot-house plants. They also do great damage to shade trees. They are kept in check by spraying with tobacco solution, kerosene emulsion, or soap suds. Certain beetles, like the ladybug, feed upon aphids and are a great check upon their increase.

Cutworms do great damage to garden and field crops by cutting off young plants near the level of the ground. Most of the damage is not caused by the quantities of plant food they eat, but in the number of plants they destroy by merely biting through the stems. They are kept in check by birds. Robins, bluebirds, and


Fig. 110.—Bills of Birds

| | | | |
|---|---|---|---|
| 1. Loon | 6. Woodpecker | 11. Shoveller | 16. Cross-bill |
| 2. Gull | 7. Night-hawk | 12. Merganser | 17. House sparrow |
| 3. Turnstone | 8. Avocet | 13. Swallow | 18. Dowitcher |
| 4. Crow | 9. Curlew | 14. Creeper | 19. Pelican |
| 5. Hawk | 10. Grosbeak | 15, 15a. Flycatcher | |

meadowlarks are great enemies of the cutworm.

**Bird Adaptations**

Birds that feed on plant seeds have stout, wedge-shaped, pointed beaks. The sharp point of the beak enables them to readily select and pick up their favourite seed from amongst a mass of other things. The stoutness of the beak gives strength for crushing the hard part of the seed so as to expose the kernel within. The crossbill is common in the coniferous forests of Canada. This bird has a scissor-like bill, whose ends cross over (hence the name) ; it feeds on the seeds of the pine and fir. The shape of the bill enables it to slice off the seed-cases from the cones.

**Teeth of Herbivora**

Herbivorous mammals are specially adapted to graze upon grass or browse on tree foliage, by having sharp chisel-like teeth in front. They have grinding teeth set rather far back on the jaw bones for rubbing the food into pulp. These grinding teeth are adapted to the purpose by being built up of more or less vertical layers of hard and soft material. The softer material is worn down more quickly than the harder and the grinding surface is thus always rough. This helps in the grinding of food into pulp. Since herbivorous animals do not need to seize active animals or pierce their flesh, they have no fangs. Some

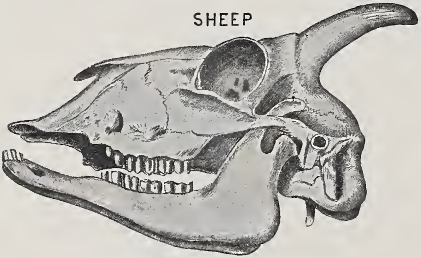



Fig. 111.—Skull of Sheep
Notice the absence of front teeth in the upper jaw.

of them possess no cutting teeth in the upper jaw. The tongue or the lip is then somewhat altered to assist in gathering the food. Some plant-eating animals gnaw the bark of trees, or the larger seeds of plants. Such animals are called rodents. Their special adaptation is the long, curved, constantly growing front teeth, and the somewhat hand-like nature of their front paws, which are used to manipulate their food while eating. Squirrels, beavers, and muskrats are examples.

**Adaptations to Secure Animal Food**

Many insects feed upon animal food; for example, the ladybug feeds on aphids. Quick motions, as they dart hither and thither, enable them to catch the aphids. Mouths which can bite enable them to devour their prey.

The Ichneumon fly does not itself feed upon insects, but the female lays her eggs in the bodies of caterpillars, and when the young larvae hatch out they destroy their host by feeding upon its tissues. These two insects are exceptionally useful to man, since they constitute a powerful natural check upon the undue increase of harmful insects; e.g., the ichneumon flies are very helpful in controlling the tent caterpillar moth.

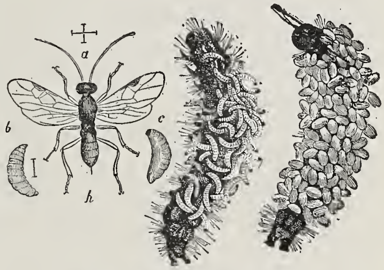


Fig. 112.—Ichneumon Fly

*Fishes* are adapted to secure their food by swift darting movements and by the possession of inward-curving, sharp teeth which enable them to grasp their slippery prey firmly.

*Frogs* feed largely upon flies and slugs. A frog's mouth is well adapted for capturing live prey. Small sharp-pointed teeth on the upper jaw help to hold the captive firmly. Its forked and sticky tongue, fastened to the front of the mouth, with its loose end pointing towards the throat, can be rapidly thrown out of the mouth and drawn back again. This enables it to whisk flies into its mouth with unbelievable rapidity.

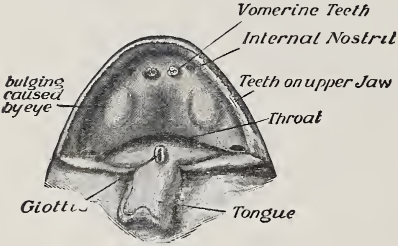



Fig. 113.—Mouth-cavity of Frog

*Snakes* feed largely upon live frogs, earthworms, and small mammals. They never feed upon carrion. They are capable of swallowing animals considerably thicker than their own body. They are enabled to do this because of the loose elastic jointing of their jaws which gives them an exceptionally wide gape. The prey cannot escape owing to the sharp inward-curving, spine-like teeth.

*Carnivorous birds* are adapted to secure their prey by strong, hooked claws which act like grappling irons. Some birds of prey can strike powerful blows with their doubled-up claws, that stun or kill their prey. Their sharp, curved beaks enable them to tear the flesh off the body which is firmly grasped in their talons.

*Carnivorous mammals* have sharp, hooked claws for seizing their prey, or hanging on to it until they are able to kill it. They are splendidly equipped with powerful springing muscles which enable them to leap upon their victim. Long, sharp fangs enable them to

inflict wounds deep enough to kill rapidly and cleanly. The front chisel-like teeth furnish the means of tearing the flesh from the bodies of their kill. The jagged outline of the back teeth assists in the mastication of

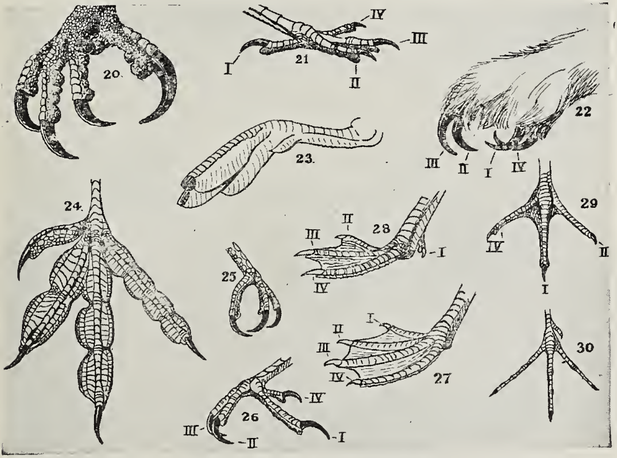



Fig. 114.—Feet of Birds

20. Hawk-type
21. Passerine
22. Owl
23. Grebe
24. Coot
25. Three-toed Woodpecker
26. Four-toed Woodpecker
27. Cormorant
28. Typical Duck
29. Plover
30. Snipe

fleshy food and also to hold the prey. Some carnivorous animals feed upon burrowing animals. Such ones have strong, blunt, chisel-like claws which enable them to dig out their prey.

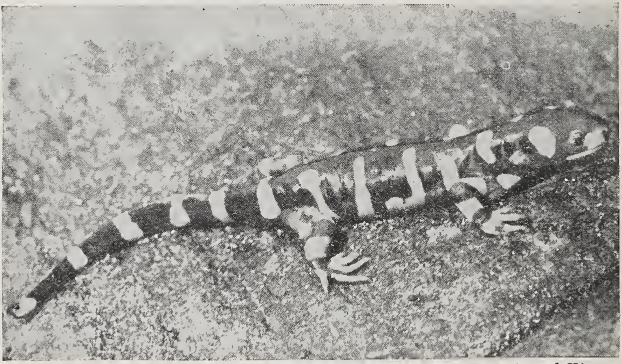
As we have already seen, one of the great distinguishing features of animals is their power of moving from place to place. There are three environments within which animals may be required to move, viz., the water, the land, and the air.

**Adaptations for Locomotion**

**Locomotion in Water**

*Fishes* are adapted to move in the water by the modification of their tails. This is their organ of propulsion. The adaptation consists of a flattening and widening of this organ and the development of strong muscles to move it. The fins are not used for propulsion, but merely serve to balance the animals and to control the depth at which they wish to move. In addition, their bodies are specially shaped to offer the least resistance to motion.

*Salamanders* have a long, flattened and sometimes fringed tail which increases the surface area of the



*Courtesy American Museum of Natural History*

**Fig. 115.—Spotted Salamander**

tail. Sweeping the tail from side to side propels them. The feet are used for balancing and controlling depth.

*Frogs* are provided with large and muscular hind legs with webbed feet. They propel themselves by jerking these in and out. They obtain balance by the use of the front legs which are small and webbed.

*Ducks* propel themselves with their strong webbed

feet which are set far back on the body to give them greater leverage and freedom of movement. The feathers are prevented from becoming wet through immersion in the water, by an oil. The ducks apply this oil with the beak. It is secreted by glands situated near the root of the tail.

*Grasshoppers* are equipped with three pairs of jointed legs for walking, and have special foot adapta-

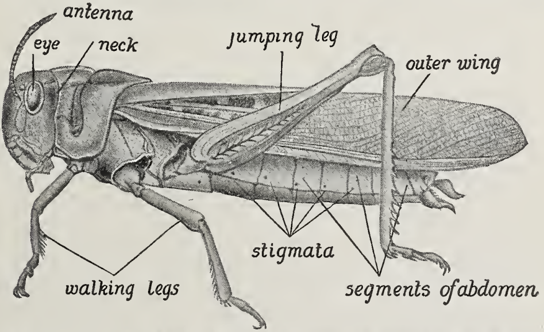



**Fig. 116.—Side View of Grasshopper (somewhat enlarged)**

tions for climbing. The hind pair of legs is enormously lengthened and very muscular. This adaptation gives them great jumping powers.

**Locomotion on Land**

*Snakes* have no limbs. They are, however, capable of moving quite rapidly along the ground and of climbing trees. They are enabled to do these things by "scutes" on the under side of their bodies. Scutes are crescent-shaped scales which can be moved forwards and backwards by muscles attached to the ribs. When opened they grip the ground, and a somewhat writhing movement of the body helps the motion by alternately pulling and pushing the body along.

*Rabbits* are capable of moving with great speed. They are also able to change direction suddenly. The adaptations enabling them to do these things are:

1. The powerful muscles of the loin and body.
2. The habit of resting on the whole length of their hind feet.

The motion is a series of bounding springs. The habit of resting on the whole length of the feet gives the rabbit the power of starting quickly from the rest position, the folded portion of the hind limb acting like the quick release of a compressed spring.

*The horse* has a wonderful adaptation of his limbs for locomotion. Horses really walk not on their feet but upon the nail of what is really their middle finger. The knee and hock are properly the wrist and ankle joint respectively. In addition they have very powerful muscular development of the spinal and leg muscles.

**Locomotion in Air**

Motion through the air is obtained in three ways: by flying, banking, or volplaning. Insects, birds and bats use the flying method. Birds often use banking. Watch a hawk circling round without flapping his wings. Flying squirrels volplane.

*Butterflies* are true fliers. However, they are not strong fliers. All butterflies have two pairs of wings. The propulsion is obtained by fluttering the hind pair whilst the function of the front pair is to balance the insect. There are three main sorts of wings seen on insects: gauzy wings, like those on the dragon-fly and house fly; scaly wings, like those possessed by the butterflies and moths; and horny wings such as those seen on beetles.

*Pigeons* also are true fliers. Their special adaptations for flight consist of:

1. A modification of the fore limbs into organs called the wings. In adapting the fore limbs for flying the bird has lost most of the hand parts, retaining only two small bones which may be felt on the pigeon's wing.

2. Covering the modified wing and enlarging its surface by a special arrangement of feathers.

3. The modification of the breast bone by the addition of a bony projection called the "keel". This serves as an attachment for very powerful muscles which move the wings during flight.

4. In addition, hollow bones and sacs filled with air make the body more buoyant and increase the rate of respiration.

5. The shape of the body offers small resistance to motion through the air.

Fig. 117.—Vampire Bat of South America

6. The tail is specially modified and equipped with feathers to help balance the body and control direction.

*Bats* are the only mammals which have properly solved the problem of aerial locomotion. The wing of the bat differs entirely in plan from that of a bird. A bat's wing is a modification of the hand rather than of the whole arm. The fingers of the hand are enormously enlarged and a thin membrane stretches over them. This membrane reaches the body near the hind feet. Propulsion is obtained by flapping the wings. The breast bone is not keeled as in the case of birds. The peculiar construction of the wing, by using the fingers as a frame over which to stretch the skin, gives to the bat his scientific name of Cheiroptera, which means "hand-winged".

## QUESTIONS

1. Name three animals (one a mammal, one a bird, and one an insect) that show distinct adaptations in body form which make them effective in getting their food.
2. Name three ways in which carnivorous and herbivorous animals differ from each other.
3. What food habits are characteristic of the following animals and how are their mouth parts adapted to conform with these habits: (a) aphis, (b) frog, (c) snake, (d) night-hawk, (e) hawk?
4. Name three distinct examples of the adaptation in the form of the locomotive organs to the life habits in each of the following classes of animals: (a) land animals, (b) aquatic animals, (c) flying animals.
5. Insects cause great damage to crops. Name six common insects which damage our crops and show (a) what natural means keep them in check, (b) what artificial means may be employed for the same purpose.
6. Write a note on the economic importance of birds.
7. Name five distinct adaptations of the body parts of herbivorous animals which are definitely related to their food habits.
8. What special adaptations of ladybugs and ichneumon flies make them valuable to agriculture?
9. Compare the locomotive adaptations in the following groups:
   - (a) fish, salamander, frog, duck.
   - (b) grasshopper, snake, rabbit, horse.
   - (c) butterfly, pigeon, and bat.

## CHAPTER XXV

### ANIMAL ADAPTATIONS—Continued

Four main types of protective adaptations of animals will be considered. Animal bodies are soft and require

**Protective Covering** protection. This object is accomplished by many devices. Some animals produce a horny substance within which they encase their bodies. Grasshoppers, beetles, crabs, and lobsters are some examples of animals adopting this mode of protecting their delicate parts from injury. Fish and snakes achieve the same end

**Fig. 118.—"King of Beasts"**
Note the greatly developed canine teeth and the powerful claws.

by casing their bodies with overlapping segments of *keratin,* which we call scales. Oysters, clams, and other similar molluscs abstract lime from the water and build it into a shell for the same purpose. Birds clothe themselves with feathers. No other animal uses feathers for body protection. Mammals make use of a more or less soft covering called hair. This is largely for protection against cold, but it also protects very efficiently against injury from scratches or blows. It is often modified in different animals so that it goes under several names, for example, fur, wool.

**Fig. 119.—Four Walking Stick Insects**

Mammals which live in the seas have been forced to adopt some means of preventing too great a loss of body heat into the water. Such animals possess a complete layer of fat underneath the skin. This is called blubber. It is found in whales, seals, walruses, and others.

All animals are surrounded by enemies. Every animal must be constantly on guard or it will fall a victim to an enemy. One of the greatest needs of animals, therefore, is the power of concealment. They obtain this power in many ways. "Freezing," or the power of remaining motionless at the slightest hint of danger, is one method of securing this much desired concealment.

Another method is that of *protective colouration.* This method takes several forms. It may take the

form of making the animal harmonize with its surroundings. The white colour of the polar bear and the Arctic fox makes them harmonize with the ice and snow of their environment.

**Protective Colouration**

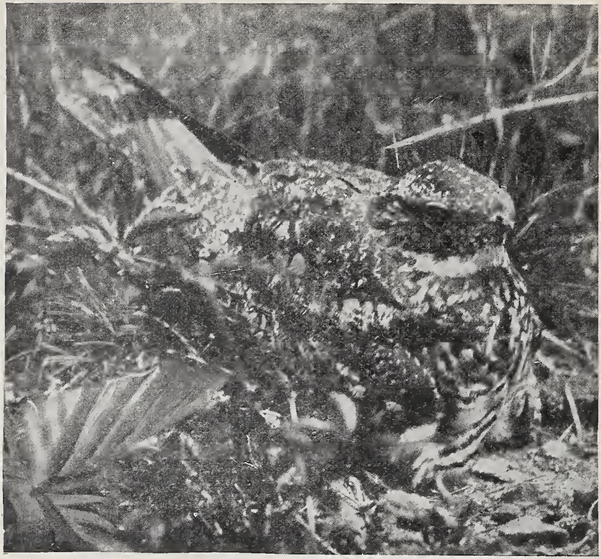
The colour scheme of the ruffed grouse (partridge) gives it perfect harmony with the willow logs on which it so often suns itself. The gaudy colours of the tiger harmonize well with the surroundings of its native haunts. Notice also how animals living in sandy places are so often light brown in colour. Another way in which concealment is obtained is by having dark back colours combined with lighter-coloured underparts. This counteracts the shadow thrown by the animal's body and thus assists in the concealment.

Many animals do not migrate with the season. In countries where snow lies on the ground throughout the winter, an animal inconspicuous during the summer would be very noticeable against the snow.

**Seasonal Changes in Colour**

This is combated by changing from a summer to a winter dress. Many Canadian animals do this very thing. The Arctic or Varying Hare (commonly called the rabbit) is greyish-brown in the summer but white in the winter. The Ptarmigan is an example of a bird that accomplishes the same feat. The weasel is brown in summer, but white in winter.

*Mimicry* is another mode of obtaining protection from enemies. Many animals are coloured to imitate some other animal which may sting, or have a nauseating taste, or be otherwise distasteful to some other animal. Because of this they are often passed over by animals that have seen them but do not care to take risks. The harmless clear-winged moth closely



Courtesy National Audubon Society

Fig. 120.—Night-hawk Brooding Young

Note the protective resemblance between the bird and its surroundings.

resembles the hornet in colour and so often escapes attack.

**Adaptations for Attack**

Many animals have adaptations which enable them to attack their enemies when discovered by them. Among these we may cite the sharp fangs and retractile claws of the carnivores; the horns of many hoofed animals and the sting of the wasp; the discharge of an offensive fluid by the skunk and its cousins.

*Protective habits*—Many animals dig burrows, for example, gophers, spermophiles, badgers. Some

build nests like the birds, wasps, bees. The beaver dams up the stream and forms a small lake in which he constructs a house. The muskrat has a similar habit of building a house, but does not make a dam. Instead, he uses the shallower bays of lakes.

Many other instances could be given and many other forms and types of adaptations. Look for them yourselves, and you will discover many more.

**Artificial Adaptations**

We have noticed that nature modifies plants and animals to suit special conditions of their environment. Similarly, man has learned how to modify many characteristics of his domesticated plants and animals, the better to satisfy his needs. This may be considered as an artificial adaptation. The process is an imitation of what goes on in nature and is a most important contribution of scientific knowledge towards the welfare of the world. Thanks to the discovery of fundamental biological laws by such scientists as Darwin, Mendel, and Huxley, skilled and patient workers are now producing new varieties of plants and animals, and improving existing types. This has become an important branch of scientific agriculture. So far the results, although attained by slow and tedious work, have been spectacular. Such wonderful workers among plants as Luther Burbank have produced modified forms like seedless oranges, white blackberries, spineless cacti, and a host of other new and strange plants.

In Canada magnificent work has been done in improving wheat and other grains. The outstanding men in this field are Dr. William Saunders, who first produced Marquis wheat in 1892, and his brother Dr. Charles E. Saunders the cerealist, who carried out further the work which, in 1904, gave the world the

present Marquis wheat, so widely known in Western Canada. All this wheat has been produced from a single head of wheat selected by Dr. Saunders at the Central Experimental Farm of the Dominion Government at Ottawa.

Many other similar results might be cited. Find out some of these for yourself. It is due to artificial selection and cross breeding, patiently and deliberately carried out, that we have our different types of cattle, sheep, hogs and other farm animals.

The creation of a demand for bacon-producing hogs, in place of the lard hog type, in a few years resulted in a complete change in the hog population of the Ontario farms. The lard hog gave place to the bacon type. Then improvement by careful selection was carried on until the desired result was secured.

## QUESTIONS

1. Name four animals (one insect, one mammal, one bird, and one fish) showing distinct adaptations in body covering, which afford protection against injury either from the environment or from other animals.

2. Name three adaptations among animals which serve to protect them from extremes in temperature.

3. What is protective colouration among animals? Give examples of animals (one each) using this method of protection under the following headings:
   (a) Harmonizing with surroundings.
   (b) Changing colour with the seasons.
   (c) Mimicking another animal.
   (d) Mimicking some plant structure.

4. What is a protective habit? Give four examples from the common wild animals of the Province.

5. What are artificial adaptations? Name some scientists whose work has placed in the hands of animal and plant breeders a very important method of improving the breed and creating new varieties of plants and animals

6. Write a note on the value to Canadians of the work of Dr. William Saunders and his brother Dr. Charles Saunders in making a new variety of wheat.

7. Discuss under the following headings, giving examples, the general structural differences that adapt aquatic and terrestrial animals to their respective modes of life: (a) general bodily form, (b) methods of locomotion, (c) securing of oxygen (see Chap. IX), (d) protective devices.

## PART FIVE

## ENERGY

# CHAPTER XXVI

## THE NATURE OF ENERGY, ITS MANIFESTATIONS AND TRANSFORMATIONS

In a general way, most people are familiar with the term energy. We speak of an energetic person. Teachers often state in their reports that a certain pupil would do better if he or she displayed more energy.

**The Nature of Energy**

In such familiar cases the idea of energy is closely linked with another idea, namely, work. In studying energy, we must try to be a little more exact in our expression and come to an understanding of what we mean by work.

In physical science, work has a very definite meaning which often seems to have little relation to the more general idea of work. By the term, the physical scientist means that which is done when a force acts upon a mass of matter and causes it to move through space. It is essential to note:

1. That we cannot have work without the action of some force.

2. That a force does not do work by merely acting on a body. It must cause the body to move.

It often happens, however, that a force acts upon a body but does not cause it to move. For example, a boy may try to move a heavy box or stone and fail to do so. It is quite clear that he is exerting force, for he soon begins to feel tired. In such cases, the scientist says that a stress or strain is set up in the

object of the boy's effort. Now this ability to exert force is due to something which the scientist calls energy. What this mysterious thing called energy

(c) Brown Bros.

**Fig. 121.—A Tractor Pulling Fourteen Bottoms**

is, we do not really know. We do know, however, that among other things

1. Energy can do "work".
2. Energy must act upon matter before we can be aware of it.
3. Energy shows itself in many forms.
4. Energy may be transferred from one body to another.
5. Energy may be transformed from one kind of energy into another kind.

Energy, then, may be defined as the "capacity for doing work".

Energy exists in the universe in many different forms. It is very important to realize that all these forms are really one and the same thing, and not different things. That is, they are all capacities for doing work. At first it seems to be rather difficult to realize that such dissimilar forms as heat, electricity, vital

**Forms of Energy**

**Fig. 122.—Exhibition of Energy in Plants**
These fern plants in growing have broken their way through concrete. (After Stone.)

energy, are not fundamentally different things, but are simply varying forms of energy.

The principal forms in which energy is found in the universe are: vital energy, chemical energy, heat, light, electrical energy, magnetic energy, energy of elasticity, energy of cohesion, radiant energy, and mechanical energy, which may be displayed as potential, kinetic, or strain energy. Let us now glance at a few of these forms or manifestations of energy found in the universe.

*Vital energy* is the form of energy possessed by all forms of living things, which provides them with their capacity to do work. Man makes consider-

able use of his own vital energy and that of other living things in accomplishing much of his work.

*Chemical energy*—All substances possess this energy in greater or less amounts. It is the possession of stored-up chemical energy which makes some substances so much more active than others under certain suitable conditions. Explosives, for example, possess large amounts of this form of energy stored within them, which can become very active when conditions are so arranged that the "explosion" can take place. The value of fuels and foods lies chiefly in their stored chemical energy.

*Heat energy* is a form of energy which man constantly uses, or encounters. It differs completely from the chemical energy just discussed, the main difference being that heat energy is generally readily perceived by the senses, while chemical energy is not. When we use chemical energy, we do so by first converting it into heat or electricity. The main source of heat energy is the sun, which as we shall see later is the source of all energy on the earth.

*Electrical energy* is another type of energy with which we are, in this day, very familiar. It is very different, in most of its aspects, from vital, chemical, or heat energy.

*Light energy* is the energy upon which most of the activities of plants and, therefore, animals depend. It may also be made to do mechanical work. In its nature, it resembles both the heat and the electrical forms of energy. Our principal source of light energy is, of course, the sun.

*Magnetic energy* is a form of energy of great usefulness to man. It is very intimately related to electrical energy, but is not the same. It is used by man to guide his ships, to generate electrical energy,

and to operate many of his most useful common appliances; as, for example, door bells, lifting devices, telephones, radio, loud-speakers, telegraph instruments. The principal source of supply is the earth's magnetism, the ultimate source of which is due to the radiant energy received from the sun.

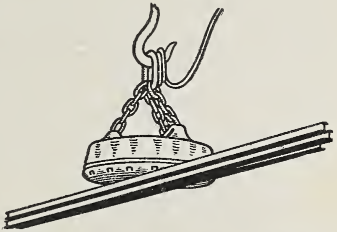


Fig. 123. — With Electro-magnets similar to this one you can lift several tons

*Mechanical energy* —This term includes the three forms of energy which are directly concerned in the study of machines, namely, potential, strain, and kinetic energy.

*Potential energy* is the capacity for work which a body has because of its position. For example, suppose you raise a stone from the ground to a table, will it possess any energy? It will, for if the table be removed it falls to the ground and, in so doing, overcomes resistance, as you can prove by holding something in its path. It is quite certain that a stone on the ground and one raised above the ground are quite different things when considered from the point of view of their ability to work. This ability to do work, which anything gains when placed in proper position, is called potential energy. It is often made use of by man, as in the case of water held behind a dam, or in that of the monkey of a pile driver.

*Strain energy* is the capacity which elastic bodies possess for doing work by reason of their size or shape having been changed. Their elasticity enables them

to recover their original size and shape, and, in doing so, they overcome resistance. This is well illustrated by the spring of a clock. In winding up the clock, we change the size and shape of the mainspring and thus store up energy. This stored energy is released as the spring unwinds, and sets in motion the hands of the clock. Strain energy is often grouped with potential energy. They are, however, different forms of energy. Potential energy depends upon some outside force, most frequently gravity. Strain energy depends on plasticity, which is a distinguishing property of material composing the body. It has nothing whatever to do with any outside force. Strain energy is very useful to man. The closing of the valves of an automobile engine by springs is an example of its useful application.

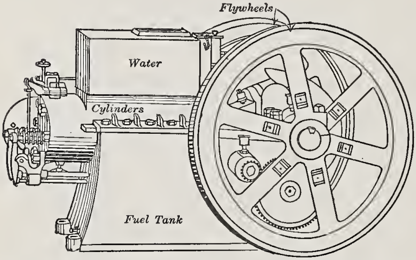


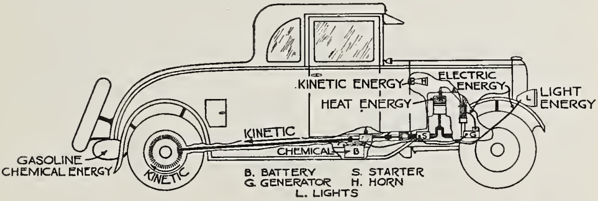
**Fig. 124.—Flywheels on a Gas Engine have Kinetic Energy when in Motion**

*Kinetic energy* is the capacity for work possessed by a body by reason of its motion. A good example of kinetic energy is the case of a rifle bullet. When in the rifle, a bullet possesses no kinetic energy, but when fired from the rifle it gains great velocity and hence considerable kinetic energy. This becomes evident by the destruction it causes when the bullet strikes its target.

It is of the utmost importance to understand clearly that each of these forms of energy may be converted

into some of the other forms. Many of these conversions may be made directly from one kind into another. Some must pass through several changes before finally appearing in the desired form. An important fact to remember is that all forms may be changed directly into heat energy. In fact the

**Transformations of Energy**




CHEMICAL ENERGY OF THE GASOLINE IS CHANGED TO HEAT ENERGY IN THE ENGINE WHICH PRODUCES KINETIC ENERGY, MOST OF WHICH GOES TO THE WHEELS. SOME IS CHANGED INTO ELECTRIC ENERGY BY THE GENERATOR AND STORED AS CHEMICAL ENERGY IN THE BATTERY. THIS CHEMICAL ENERGY IS CHANGED TO ELECTRIC ENERGY IN THE STARTER AND THERE TRANSFORMED INTO KINETIC ENERGY. SOME CHEMICAL ENERGY IS CHANGED TO ELECTRIC ENERGY AND HEAT THROUGH THE IGNITION SYSTEM AND ALSO TO LIGHT ENERGY IN THE LIGHTS.

**Fig. 125.—Transformation of Energy**

tendency of all forms of energy is to transform finally into heat. The changing of one form of energy into another is called a *transformation of energy.* It is very interesting to trace back the changes which have occurred in the forms taken by energy until we arrive at the origin.

Take, for example, the light of an electric lamp. The light energy was the result of the heat produced by an electric current overcoming the resistance of a thin metal wire; the electric current was due to the transformation of magnetism and kinetic energy in a generator; the kinetic energy in the generator may have been due to the conversion of the potential energy of water stored in a dam into kinetic energy of a tur-

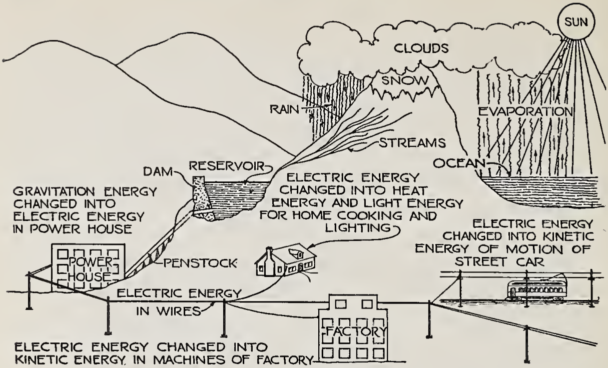



**Fig. 126**

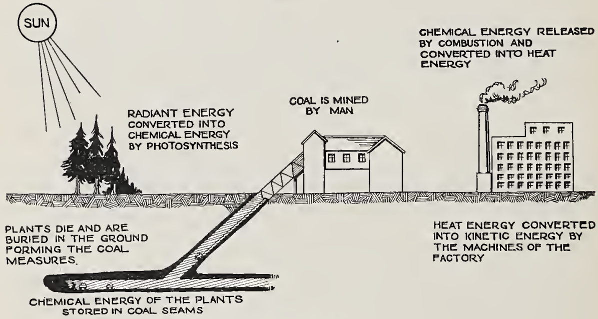



**Fig. 127**

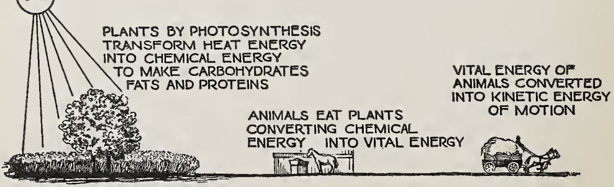



**Fig. 128**

**Diagrams illustrating the transformation of energy.**

bine; the water came from the clouds, and these were formed by the condensation of moisture which had entered the atmosphere by the agency of the heat energy of the sun.

Again, consider the transformation of energy in a locomotive. Its kinetic energy (i.e. motion) is due to the pressure of steam in the boiler, which acts on a piston and is transferred to the wheels. The steam came from the water through the heat from a fire, which again was due to the transformation of the chemical energy of the coal into heat energy; the coal received its energy from the vital energy of the plants from which it was formed; the plants, in turn, transformed the energy of the sunlight into chemical energy which was again transformed by them into vital energy. So, again, we see that the sun is the ultimate source of the energy which drives the locomotive.

One of the great lessons to learn from tracing these transformations of energy is that in every case we must have some form of energy to start with. We cannot create energy. Now just as we cannot create energy, so we cannot destroy it. These results are summed up in one of the fundamental principles of science. This is the *Principle of the Conservation of Energy,* which states that "Energy can be neither created nor destroyed, but it may be transformed from one kind to another".

There are cases in which we do seem to have destroyed energy. If, however, these are carefully investigated, we find that the energy which has seemed to disappear has, in reality, only been transformed into another kind. Sometimes it has been claimed that some one has discovered a means of creating energy. Always, however, more careful investigation has

shown that they have just discovered another source from which to get energy which was already in existence.

## The Sun As the Source of Energy Used on the Earth

At the close of his career, George Stephenson, the father of railroading, was walking with a great lawyer in the gardens of Sir Robert Peel's country home. A railway train was seen approaching. Turning to the lawyer, Stephenson suddenly asked, "What drives that train?" "Oh, some canny Newcastle mechanic," replied the lawyer. Swift came the reply of Stephenson in his broad Northumberland dialect, "Thou art wrong, 'tis bottled sunshine."

**"Bottled" Sunshine**

This is a picturesque but quite correct view of one of the greatest truths discovered by the aid of science. All the energy for the vital processes of plants and animals and all the energy for industry comes, or has come, to the earth from the sun. The sun is a hot body and like all hot bodies is constantly emitting radiant energy. This radiant energy from the sun traverses the space between the sun and the earth in the form of waves at the terrific speed of 186,000 miles per second. On reaching the earth it is transformed into light energy and heat. As we have seen, those plants containing chlorophyll transform the energy of sunlight into chemical energy and use it to manufacture food from air, water, and soil. This food they assimilate and convert into wood, which retains some of the energy derived from the sun as chemical energy. The plants thus become great collectors of the energy so plentifully poured out from the sun.

The plant life of the earth, therefore, acts like a great

reservoir to collect the sun's energy. But plants, like animals, die. What becomes of the energy they have collected during their lifetime? Some of this energy they have transformed into heat energy, and part they have converted into vital energy with which they carry out their life functions. A considerable quantity has been used by the animals to be transformed into animal tissues and vital energy. Much of it, however, remained stored as chemical energy in the woody tissues of the plants.

**Plants as Reservoirs of Energy**

During long ages countless numbers of plants have flourished and died. Some of them died under such conditions that the woody parts of their bodies were soon covered over by mud, and slowly converted into coal, oil and gas. Such preserved plant bodies form our great coal, oil and gas fields, from which we obtain most of the energy to operate our industries.

Thus we see that:

1. The sun is the provider of energy.
2. Plants are collectors of energy.
3. The earth is the great storehouse of energy.

But there are other available sources of energy as, for example, running water, tides and wind.

We have already seen that running water is the result of the condensation of atmospheric water vapour into rain, snow and hail. The source of atmospheric vapour, we discovered, was the evaporation by sunshine of the oceanic and inland waters of the earth. Thus the energy of running water is really due to the sun's energy. Similarly, winds are simply great natural convection currents in the air, which are started by the unequal heating of the earth by the sun. So again we are compelled to recognize that the kinetic energy of the wind is the gift of the sun.

Other sources of energy found upon the earth are the internal heat of the earth, radioactivity and atomic energy. These again must have originally received their energy from the sun; for the earth was once part of the sun.

We are thus compelled to reach the conclusion that actually there is only one important source of energy, that is, the sun. Also we learn that the sun's energy is transformed and made available to us through four main channels:

1. The chemical energy of foods.
2. The chemical energy of coal, wood, petroleum and gas, or, to use a comprehensive term, fuels.
3. Water power.
4. Winds.

## QUESTIONS

1. Define energy. What five important things do we know about energy?
2. Name at least six of the principal forms of energy. Point out two useful applications of each form.
3. What is the important difference between potential and strain energy? Give an example of each being applied in a practical way.
4. What is meant by the term "transformation of energy"? Outline the transformation of energy which takes place in an automobile.
5. Show that the energy possessed by animals and plants and used by man comes from the sun.
6. What did Stephenson mean by saying that the train was driven by "bottled sunshine"?
7. Trace the light given from the electric lamp to its source in the sun.
8. How do plants collect the sun's energy?
9. How is energy stored in the earth?
10. What are the four main channels through which the sun's energy is made available to us?

## CHAPTER XXVII

## ENERGY IN RELATION TO MAN

One of the most striking differences between civilized and uncivilized peoples becomes apparent in the manner in which they do their work.

The extensive use of machinery adapted to collect and use the great natural sources of energy is one of the distinguishing features of modern civilization. Primitive peoples make very little use of such devices; they depend almost entirely upon their own vital energy and that of their domesticated animals to operate their simple and crude machines. There is no doubt that, according to modern standards, the more civilized a people becomes, the more perfect is its control and use of energy.

**How Man Obtains Energy**

The adaptation of energy from one of the various natural sources is usually spoken of as *Generation of Energy.* This term is rather unfortunate since it gives the impression of making energy of one sort or another. This, we have already seen, cannot be done. All that man does when he is said to generate energy is to transform one kind of energy into another more suitable to his needs. As nearly everyone speaks of these transformations as the generation of energy, we also shall use this term. It must be remembered, however, that man never makes electricity, or heat, or any other form of energy.

There are many ways in which man generates energy. The most important methods at present in

use may be classified into three great groups: mechanical, chemical, and electrical.

**The Mechanical Generation of Energy**

The most common devices used by man in the mechanical generation of energy are windmills, water powers, water wheels and turbines.

*A Windmill* is a device by which man converts the kinetic energy of the wind into some other form of energy. Windmills are said to have been invented by the Arabs and introduced into Europe about the time of the Crusades. Their action, as well as their advantages and disadvantages, have already been discussed in Chapter V.

**Water Powers**

Water powers are now one of the most important sources of energy. They have already been discussed and their growing importance pointed out in Chapter XIV. It remains here to consider some of the principal devices by which man transforms their stored-up energy to a form suitable for his use.

*Water wheels* are very ancient energy-generating devices. The older types are the "Overshot" and "Undershot" wheels.

The *Overshot wheel* consists of a large wheel with compartments called "buckets" arranged around its circumference. Water flowing from some point above the wheel is allowed to fall into these "buckets". This alters the balance of the wheel, causing it to revolve slowly.

The *Undershot wheel* consists of a wheel having blades projecting from its circumference. When set in such a position that a stream of swiftly running water strikes against its lower blades, the wheel is forced to revolve. Neither of these wheels is much used to-day, because the amount of energy they can

deliver is too small for modern requirements. They have been almost entirely displaced by the Pelton Wheel and the Water Turbine.

The *Pelton wheel* is driven by delivering a jet of water at great speed into double cup-shaped buckets bolted to the circumference of the wheel. It delivers a large amount of energy with a surprisingly small consumption of water.

*Water turbines* are, however, the most important type of water wheel at present in use. It is the development of this type of water wheel that has enabled the hydro-electric generation of electricity to attain its present enormous volume. There are many very large turbine installations in Canada. Those at Chippawa (Ontario), Gatineau River (Quebec), Winnipeg (Manitoba), Ghost River (Alberta), and at Bonnington Falls (near Trail, B.C.), are among the most important.

**The Chemical Generation of Energy**

By far the greater amount of energy used by man is produced by transforming the chemical energy stored in fuels, food and other substances, into heat and electricity. This is most commonly accomplished by some form of oxidation. We have already seen that the vital energy of all living things is generated by the slow combustion of their food within the cells of their tissues. The bodies of living things, then, may be considered as machines for the generation of energy by chemical action.

The most common method of generating energy is by the combustion of fuels. These fuels may be solid, like wood and coal, or they may be liquid like gasoline, crude oil, or alcohol, or, again, they may be gaseous, like natural gas, coal gas or acetylene. A familiar device for generating heat energy by chemical action

is the steam engine. It must always be remembered that the energy which drives the steam engine is not the steam, but the heat which is in the steam. Because the heat was produced in a separate device called a boiler and transferred by the steam to a steam engine, we call steam engines "external combustion engines". The boiler is a device whereby the chemical energy stored in the fuel is released in the form of heat by combustion. The steam engine is a separate device by which the heat energy within the steam is transformed into kinetic energy and used for whatever purpose required.

*Internal combustion engines*—These are familiarly but wrongly called gas, gasoline, or oil engines. In reality they are heat engines. They differ from external combustion engines in that the chemical action of combustion takes place in their cylinders and not in a separate machine. This does away with a great source of loss of heat energy during its transfer from the boiler to the cylinder. In consequence of this, internal combustion engines are much more efficient than external combustion engines.

The internal combustion engine is a very important modern energy-generating device. It has enabled energy to be readily available in a cheap and convenient form to small and somewhat isolated consumers, such as farmers, small towns and village communities. It has also given us rapid and cheap transportation by automobile and motor truck. It is now being developed for use on a large scale as, for example, in the Diesel engine installations on large ocean-going steamers. Recently, the Canadian National Railway engineers have perfected its use for railroad purposes, and led the world in what is already heralded as the greatest triumph in land transporta-

tion since George Stephenson's "Rocket" astounded the world about one hundred years ago.

*Chemical action* is also used to generate electricity by means of electric cells. In this case the chemical action of some liquid combining with a metal releases chemical energy which appears as electricity. The amount of electricity thus produced is so small that cells cannot be used for power production. The principal use of chemically produced electricity is to operate small devices such as bells, telephones, telegraphs, and the like. Care must be taken not to confuse the storage battery, which cannot generate electricity, with the ordinary electric cells. Storage batteries are devices used to change electrical energy into stored up chemical energy, which under proper conditions is changed back again into electrical energy.

The extensive use of electrical energy distinguishes our present age from all others which have preceded it.

**The Generation of Electrical Energy**

This is pre-eminently the age of electricity. The modern use of electricity is the result of the brilliant discovery of Michael Faraday in 1831. In that year, Faraday discovered how to transform magnetic energy into electrical energy. Every dynamo-electric machine of to-day is simply a commercial application of this great discovery. They are all designed to convert the mechanical energy of steam engines, waterfalls and gasoline engines, into electrical energy by the aid of magnets. This great discovery placed in the hands of man a new source of energy, the possibilities of which we cannot yet foresee. Whenever man requires large quantities of electrical energy—for example, in running street cars, in lighting systems, in smelting, welding, refining metals, or charging storage batteries—he always generates it by dynamo-electric machines.

*Electric lighting*—The application of electric energy to lighting is one of the greatest gifts to mankind.

**Uses of Electric Currents**

There are several methods of lighting by electricity, the principal ones being by arc lamps and incandescent lamps. In the arc lamp the electric current is made to pass through a hard carbon rod, and to jump across a gap into another one. The carbon is not such a good conductor as the wire along which the current is being delivered. This causes its passage to be resisted as soon as it enters the carbon. Some of the electrical energy is by this means transformed into heat. This heat causes the end of the carbon rod to glow brightly. In jumping across the gap the current tears off tiny particles of the glowing carbon and carries them across to the other rod in a white-hot condition. The result is the production of a brilliant light. Arc lamps are used in city lighting and in motion picture machines.

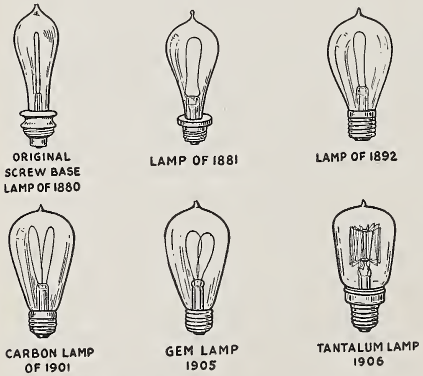



**Fig. 129.—Development of Incandescent Electric Lamps from 1880 to 1906**

*The incandescent light*—The first patent for an incandescent light was taken out in 1878 by Sir Joseph Swan in England. A little later, Thomas Edison patented one in the United

States. This was in 1879. Edison greatly improved upon the idea and made the incandescent lamp a commercial success. A few years later, Edison and Swan entered into a partnership and manufactured lamps under both patents, trading under the name of the "Edison and Swan Company", and using as a trade mark for their product the name "Ediswan". Swan died in 1924 at the age of 86.

The principle of the incandescent or "glow" lamp is simple. The great difficulty was to obtain a suitable filament. Swan used a carbonized cotton, while Edison used carbonized bamboo, in their original lamps. The present-day lamp uses a very thin metal filament, usually of tungsten. The light is due to the heat produced by the resistance offered to the passage of the current through the filament. The function of the globe is to provide a space from which the air may be exhausted or which may be filled with an inert gas, so as to reduce oxidation and also to protect the delicate filament from injury. A recent development of the vapour lamp is the "neon" tube so much in evidence to-day for electric advertising signs.

Electric irons, toasters, and stoves are devices by which electrical energy is changed into heat by passing the current through a resistance unit. This is formed by a coil of nickel-chromium wire built into the device.

*Electro-magnates* are devices for changing electrical energy into magnetic energy. This is accomplished by winding insulated wire in a coil around a core of soft iron and connecting the ends with a direct current generator.

Electro-magnates have many industrial uses. One of their most important large-scale applications is found in the electro-magnetic crane used for lifting heavy masses of iron or steel by magnetic attraction. Small

electro-magnets are essential parts of all telegraph instruments, telephone receivers, electric bells, transformers, dynamos and motors.

*Electric motors* are devices by which electrical energy may be converted into mechanical energy. They have a very wide and increasing number of applications. Some of the common forms are to be seen in barbers' clippers, vacuum cleaners, sewing machines, street cars, automobile starters and electric fans.

## QUESTIONS

1. Name three typical and distinct methods for generating energy to do man's work.
2. How do the bodies of living things generate energy?
3. Explain the statement "Man never makes electricity, or heat, or any other form of energy".
4. Why is the chemical generation of energy of such great importance in the world?
5. What is the essential difference between an internal and an external combustion engine? Why is the former the more efficient type of engine?
6. Write a note showing the great importance of internal combustion engines as modern energy-generating devices.
7. What is an electro-magnet? Name some of its uses.

## CHAPTER XXVIII

## MACHINES AND THE PRINCIPLE OF WORK

**What is a Machine?**

If you were asked to make a list of several well-known machines in common use, what would you write down? Most likely steam engines, motor cars, electric motors, binders, threshing machines, cream separators, sewing machines and many other complicated things. You would almost certainly overlook such very common and simple machines as garden rakes, can-openers, wheelbarrows, scissors, screws, hammers, chisels, your own hands, arms, fingers, legs and feet.

Why do we not ordinarily think of these simpler things as machines, whilst we always remember that the more complicated ones are machines? Perhaps it is because, somehow or other, we do not properly realise the purpose of a machine.

*What is the purpose of a machine?*—The purpose of a machine is to enable us to exert a push or pull at a desired point by applying a force at some other point. Our object in doing this is usually to overcome a resistance at the said desired point. In other words we use a machine to help us do work. The machine may help us do this in three principal ways:

1. It may multiply the effect of the applied force.
2. It may give us a more convenient position from which to apply the force.
3. It may give us an advantage of speed.

In any case no machine can possibly give us all three advantages at once. It may, however, give any two at the expense of the other one. We may, therefore, define a machine as any contrivance by which we may cause an applied force to do work.

**What is Work?**

In order to understand what is meant by *work* in the study of machines, we must remember that scientists understand something quite different from the everyday meaning of the word. Suppose you are holding a one-pound weight in your hand so that it cannot fall to the ground. Are you doing work? In the ordinary meaning of the term, yes, but the scientists say no; holding a weight in a fixed position is not doing work. Now move your hand up or down and the weight moves with it. The scientist says you are now doing work. Why? Because you are overcoming the resistance of gravity on the weight and producing motion. This is the whole idea. When scientists speak of work they mean not the effort put forth, but the motion caused when any resistance is overcome. Looked at from this point of view, work is done when we push a lawn mower, wind a clock, turn a screw, open a door, or pull a sled. On the other hand, suppose you are driving a car and it gets stuck in the mud. The passengers jump out and push hard to help the engine move the car. The car does not move, but the persons pushing the car soon begin to feel tired. They say "We worked hard to get the car out of the mud but failed." The scientist says they did no work, for if they had the car would have moved. In studying machines it is necessary to really understand this distinction between what the scientist means when he talks about work, and what is ordinarily meant by the same term.

*The Measurement of work*—We already know that

in order to express any measurement we must first have a unit. What is the unit used to express the measure of work? From the last paragraph we know that work is only done when a force overcomes a resistance and causes motion. This may be explained by the statement, work done = force × distance, or the unit of work is the work done in overcoming unit force through unit distance. Now, in the British system of measurement the unit of force is the pound, and the unit distance the foot; therefore the British unit of work is called the foot-pound. The foot-pound, then, may be defined as the work done when a resistance of one pound is caused to move through a distance of one foot. For example, if a weight of one pound be lifted through a vertical distance of one foot, then we say one foot-pound of work has been done. Similarly if a body offers a constant resistance of one pound to motion in any direction, then, if it be forced to move a distance of one foot, one foot-pound of work is done. Suppose a wagon with its load offers a constant resistance of one ton to being hauled along a level road. If a team of horses moves this wagon one foot, then the team does 2,000 foot-pounds of work. If they haul the load for a mile then they do 2,000 times 5,280, or 10,560,000 foot-pounds of work.

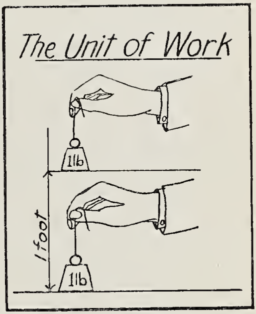


Fig. 130

We are now in a position to proceed further with our study of machines. The object of using machines is to enable us to suit the forces at our disposal to the re-

sistance which we want to overcome. The forces may be exerted by men or animals, or they may be obtained from the energy generated by one of the methods discussed in the last chapter. The resistance to be overcome may be offered by gravity, or friction, or cohesion. The first is illustrated by the lifting of heavy bodies. Hauling a train affords a good example of the

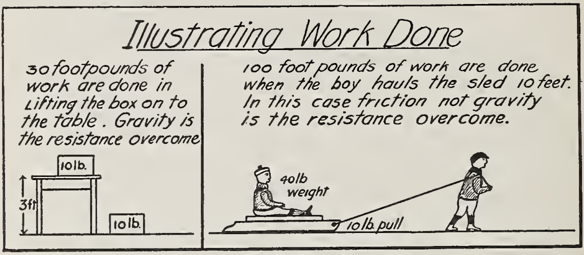



Fig. 131

second, and planing a board is an instance of the third. Some of the machines used for doing work are very complicated affairs, but no matter how complicated or how large they may be, all of them are built up from combinations of seven very simple machines. These are the lever, pulley, wheel and axle, inclined plane, screw, and wedge.

**Simple Machines**

*The Lever*—A lever is a stiff rod or bar capable of being turned about a point called the fulcrum. Levers are the most commonly used simple machines, and an understanding of the principles of levers is a great help in making use of them. They are of three classes, these being distinguished from one another by observing the relative positions of the three points: the fulcrum, the point where the force is applied, and the place where the resistance is being acted upon. *In levers of the*

*first class* the fulcrum is between the force applied and the resistance. Many common tools are familiar examples of this class of lever. The crowbar, tack lifter, scissors, blacksmith's tongs, glove stretchers, all belong to this class.

*Levers of the second class*—These have the resistance placed between the fulcrum and the point where the force is applied. One great advantage of this type of lever is that it saves space, because it gains a greater mechanical advantage in proportion to its total length than either of the other two levers. Familiar examples of this class of lever are nut-crackers, can-openers and wheelbarrows.

*Levers of the third class*—These have the force applied at some point between the fulcrum and the resistance. Levers of this class always diminish the effect of the force put on them, but increase the rate of speed at which they move the resistance. This introduces a very important principle, viz., that in all cases in which we gain some advantage we must sacrifice something to obtain it. We cannot, in machines, gain something for nothing. This is the reason why "perpetual motion machines" are an impossibility. If a machine has multiplied the force put into it, then it has most certainly lost something else—usually speed and distance.

Third class levers are particularly useful where we wish to move something quickly through space. This is accomplished by moving the more heavily applied force or effort through a smaller space than is required to move the lighter load. Familiar examples of third class levers are jibs of cranes, treadles of sewing-machines and grindstones, the human forearm, sugar tongs and firm-joint callipers.

*Bent Levers*—Sometimes the lever may be bent.

Such levers are put to many uses, but always with the same purpose in view; that is, to allow the force to change direction. This is sometimes necessary in order:

1. To gain a more favourable position from which to apply the force.

2. To transmit a force around an obstacle. An ordinary hammer is an example of a bent lever which gains for us a better position for the purpose of extracting a nail.

The brake pedal of an automobile is a bent lever which is designed to bring its force arm into a more convenient position for the driver to exert pressure upon it with his foot.

*Parts of the Lever*—Every lever has the following parts:

1. The fulcrum, i.e., the axis about which the lever can move.

2. The resistance, or load, i.e., the weight of the object or force to be overcome.

3. The resistance arm, i.e., the distance of the load from the fulcrum.

4. The force arm, i.e., the distance of the fulcrum from the point where the effort is being applied.

5. The force or effort.

**The Law of the Lever**

All levers, no matter to which class they belong, obey a general law called the law of the lever. The law may be stated thus: when any lever is balanced, the force applied times its distance from the fulcrum always equals the resistance overcome times its distance from the fulcrum.

**Experiment 60.**—*To study the law of the lever.*

*Lever of the First Class.*

*Required:* Metre stick, hardwood prism for fulcrum, set of weights.

*Procedure:* Place the metre stick on the prism so that the apex of the prism is on the 50 cm. mark. Balance the stick if necessary by coiling a piece of wire around its lighter end. Shift the coil about until balance is obtained. Put blocks under each end of the stick so as to prevent it swinging too much. Suspend a weight P by a loop of thread at any graduation. Note its distance from the fulcrum. Suspend a heavier weight W in the same manner, and slide it away from or nearer to the fulcrum until the stick is balanced again. Note its distance from the fulcrum. Make several determinations, changing the weights and lengths of arms each time. Tabulate the results and compare them.

If the metre stick be set up to act as a second and third class lever, further experiments may be carried

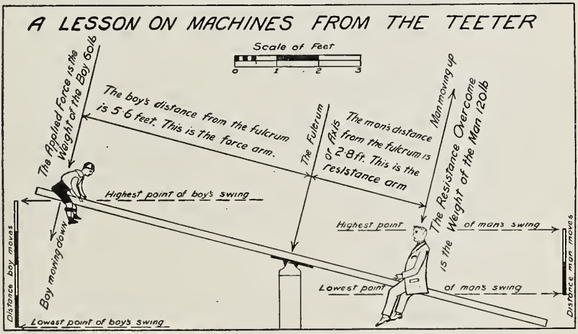



**Fig. 132**

out, which will show that the law of the lever applies equally to these classes of levers.

*Machines and the Principle of Work*—No matter how many times a machine, through its action, multiplies or lessens the force we apply upon it, the work done by the applied force is always the same as the work done by the machine on the resistance. This is the great law governing the working of all machines and known as the *principle of work.* Perhaps the most important thing to remember about machines is

the great principle *that no machine can do any more work than is put into it and that most machines actually give out for useful purposes less work than they receive.* This great truth about machines is well shown in the familiar teeter or see-saw.

*Exercise on Machines*—Study carefully the diagram of a teeter shown in Fig. 132, and answer the following questions:

How many times further is the boy from the fulcrum than the man?

How many times heavier is the man than the boy?

How much force does the boy apply?

How much resistance does the man offer to the effort of the boy?

Using the scale in the diagram, measure how far the boy can move down and how far the man can move up. Multiply these distances by the weights of the boy and the man respectively. This is the work done by each. What units will you use to express the amount of work done? What do you find out about the work done by the teeter?

## QUESTIONS

1. In the scissors shown in Fig. 133 what force must be exerted by the fingers to cut a piece of cloth offering a resistance of 12 pounds, if the edge of the cloth be 1 inch from the rivet? If the cloth be moved to a position 2 inches from the rivet, what force must now be applied by the fingers?

2. In using any pair of scissors how can you increase the effect of the force exerted by your fingers? Why?

3. In the tack lifter shown in Fig. 133 what lift would be given to a tack by a force of 12 pounds applied at a point 12 inches from the fulcrum? What force applied to a point 8 inches from the fulcrum would be required to produce the same effect on the tack? 96 lbs

4. By applying a force of 15 pounds to the handle of the pliers in Fig. 133, how much pressure would be exerted on a wire held between the jaws ¾ in. from the rivet? If this is not sufficient pressure to hold the wire, what might you do to gain a sufficient force to grip the wire firmly? Why?

5. In using the can-opener shown in Fig. 134, how much force must be applied at its handle to open a can which offers a resistance of 90 pounds to being cut? If the handle were longer would you still require to exert the same force Why?

6. What resistance does the walnut shell shown in the nut-cracker offer to being crushed, when it requires a force of 8 pounds exerted 8 inches from the fulcrum to break the shell?

7. How many times will a force be multiplied in using the lemon squeezer shown in Fig. 134?

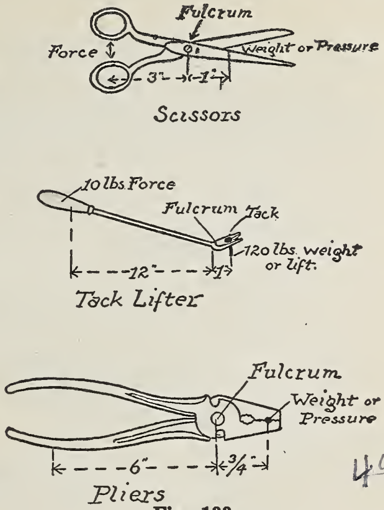



Fig. 133

4000

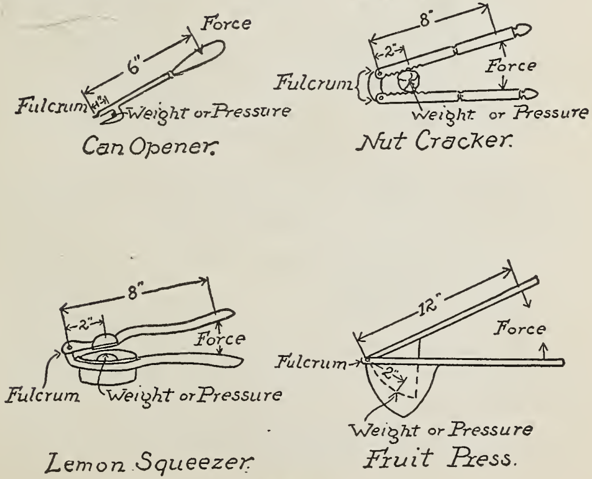



Fig. 134

8. If a resistance of 108 pounds is offered by some fruit in the fruit press shown in Fig. 134, how much pressure must be exerted on the handle 12 inches from the fulcrum? How much at 10 inches from the fulcrum?

9. In using a fork to pick up a piece of meat from a plate, what effect would the toughness of the meat have on the position of, or the pressure exerted by, the forefinger? Why?

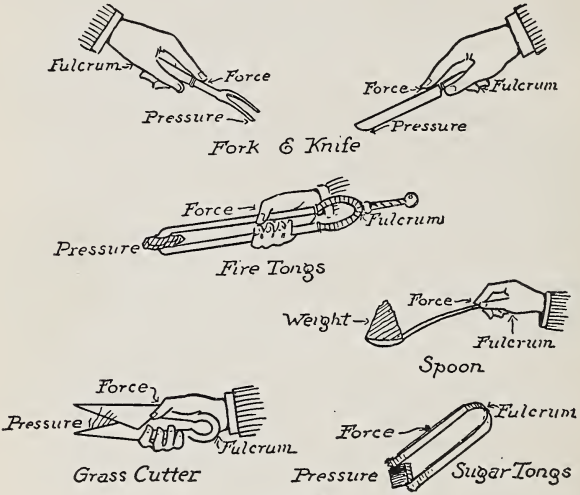



Fig. 135

10. Study the diagram of the knife in Fig. 135. Suppose the force arm to be 4 inches long and the resistance arm 10 inches long, how much cutting pressure is produced by exerting 15 pounds of force?

11. In the case of the fire tongs, suppose the hand grips the tongs 8 inches from the hinge and the coal is held at a point 20 inches from the hinge. How much pressure is required to hold a lump of coal weighing 12 ounces?

12. If the distance from the handle to the centre of the bowl of a tablespoon is 6 inches, and the distance from the forefinger and thumb to the end of the handle is 2 inches, what force will the thumb and finger exert in lifting 3 ounces of sugar held in the bowl?

13. In using a grass cutter of the type shown in Fig. 135, how could you increase the cutting pressure of the blades without exerting any more force by the hands?

14. In using a pair of sugar tongs which are 6 inches long, what pressure is exerted on the sugar by a finger-pressure of 1 pound half way down the tongs?

15. Why is the force exerted always greater than the pressure produced or weight lifted in levers of the third class?

16. Make a list of appliances not shown in the diagram, illustrating levers of the first, second, and third classes (4 for each). State why you believe them to be such.

**The Pulley**

The pulley is a very useful form of simple machine. It is really a continuously-acting lever capable of rotating completely round the fulcrum which is called an axle. Pulleys are used either singly or in combination, and they may be either fixed or movable. A fixed pulley is one whose axle is not raised or lowered when in action. Movable pulleys are always raising or lowering the position of their axles when in use. Just as we had three classes of levers, so we may have three classes of pulleys. A single fixed pulley is always a pulley of the first class and its action is exactly the same as that of a lever of the first class having equal arms. That is to say, it simply allows us to change the direction of the force, but does not alter the amount of the force.

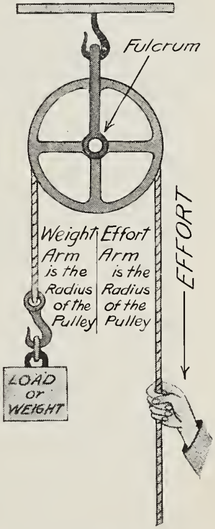


Fig. 136.—Pulley of the First Class

In Fig. 136 we have a single fixed pulley. The effort required to raise the load is exactly the same as the weight of the load. Also

the length of rope pulled down by the effort is exactly the same as the distance the weight moves upward.

Single fixed pulleys are in very common use; e.g., on well-frames they change the effort of hauling the pail from a lift to a pull. They are also found in window sashes or vertically-sliding doors, and on elevators.

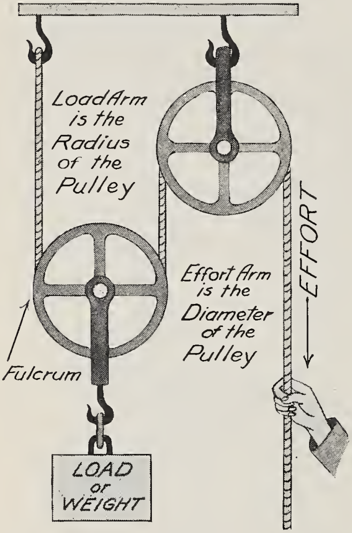


Fig. 137.—Pulley of the Second Class

Movable pulleys are always pulleys of the second or third class. A movable pulley of the second class is shown in Fig 137. Here the effort arm is the diameter of the movable pulley, and the load arm is its radius; hence the effect or the effort on the load, as in the case of levers, is doubled. Any force, therefore, applied at the effort end of the rope, produces just twice the effect on the load, but the effort moves through twice the distance the load does. This is the most useful form of pulley, and it always doubles the effect of the effort.

Fig. 138 represents a movable pulley of the third class. In this case the effort is applied at the axle of the pulley and the load acts upon its rim. This means that the effort arm is the radius of the movable pulley, and the work arm is its diameter. Since the

radius is half the diameter, then the effect of the effort on the load to be raised must, by the lever principle, be halved. In consequence the rope is only pulled up half as far as the weight rises. A pulley system arranged in this manner would require a 2 pound force to lift a load of 1 pound, but we should raise the load twice as far as we raised the pulley.

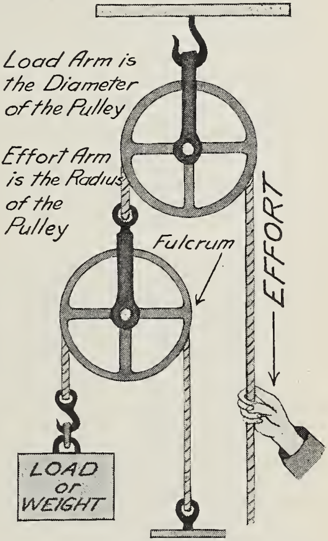


Fig. 138.—Pulley of the Third Class

If we want to gain more than twice the effect of the effort by the use of pulleys, then we must compound them; that is to say, we must work out combinations of fixed and movable pulleys that will give the effect we require. There is no end to the possible combinations we may make with pulleys, but in practice it is found that the weight of the pulleys and the friction of the many turns of rope soon begin to offset the advantage we had planned to gain. Any combination of fixed and movable pulleys is called "a block and tackle" and is a very useful simple machine by which a great deal of heavy work is accomplished with little effort.

*Experiments on Pulleys*—All the above facts about pulleys may be easily proven experimentally. To do

this, set up the pulleys as shown in the diagrams. Hang a known weight to the hook. Then attach a spring balance to the free end of the string, and by pulling on the balance raise the weight. Take the readings of the balance in each case, and record the results. Next try some combinations of pulleys that may interest you, but be sure to record the result of each combination and to make a sketch of it. The important things to record are the weight lifted, the reading of the spring balance, the distance the weight moves, and the distance the spring balance or force exerted moves.

Write out in your own words the advantage of using pulleys.

# PART SIX
# THE EARTH'S CRUST

## CHAPTER XXIX

## MATERIALS OF THE EARTH'S CRUST—ROCKS AND MINERALS

**The Earth's Crust**

The term crust was given to the surface of the earth in the days when men thought the interior of the earth was composed of hot molten rock. This is no longer believed, but it is still held that the earth's interior is hot. There are many evidences which give support to this idea. It is now held that the earth's interior is solid and

Fig. 139.—Crater of Vesuvius in Moderate Eruption

of a quite different nature to the enveloping shell of hard, cooler material which geologists call the lithosphere.

It is with this outer shell or lithosphere that we are now concerned. Let us look at it first as a whole. Nearly three quarters of it is hidden from view by a covering of water. This water is irregularly dis-

**Fig. 140.—Escarpments and Dip Slopes**

tributed over the surface of the earth as oceans, lakes and rivers. The exposed part of the lithosphere we call the land surfaces of the earth. Now, the most striking thing about the lithosphere is its great unevenness.

*Elevations and depressions of the crust*—On every hand we notice the presence of elevations and depressions. Some of these are quite distinctly very large and contain smaller elevations and depressions. These are called the major elevations and depressions. The major depressions are filled with water and are

termed *ocean basins.* The elevations form the *continental land masses.*

The major elevations of the earth's crust display many smaller elevations and depressions on the surface. These are called minor irregularities. They consist of mountain ranges, hills, plateaus, plains, valleys and the like. These again are very irregular in their nature. Some have steep and abrupt; others long and gentle slopes; many take on the aspect of long ridges, while some have a more or less rounded form. Irregularity is the great feature of the earth's crust. Nowhere on the earth's surface is there to be found any considerable expanse of perfectly level surface. The irregularities impart the distinctive character to the landscape of a region, and exert a great effect on the type of agriculture carried on there.

The universal prevalence of slopes is of great importance to the world, for they allow the water falling upon the earth to drain away to the greater depressions forming the oceans, lakes and rivers, and other water features of the globe. It is these slopes that enable water to gather kinetic energy which man uses in water powers. They are of great significance in the production of food and clothing materials, since they exert a profound influence on the practice of agriculture. Without them the earth would become waterlogged, and as a result many of our most useful commercial plants would die off. Then again these slopes allow varying degrees of light, shade and temperature to exist in the same region, thus allowing a variety of products to be found within the same area. This is of great benefit to man, for it assists him in obtaining different materials to supply his varied wants.

Many agencies have contributed to the production of these irregularities. The following is a partial list with some indication of the way they work:

1. The heated interior of the earth exerts continuously great pressure against the outer shell. This causes the greater uplifts or mountains.

2. Volcanoes eject material from the interior of the earth and so cause other elevations.

3. Earthquakes produce cracks and sometimes foldings in the earth's crust.

4. Running water and sliding ice as in glaciers carve the surface into valleys.

5. Freezing water splits the rocks and so alters the shape of the uplifts.

6. Temperature changes, through alternate expansion and contraction, break away fragments of rock.

7. The oxygen, carbon dioxide and water vapour of the atmosphere by chemical action bring about the disintegration of rocks.

There are many other such agencies, but these should suffice to indicate in some measure how the earth has come to possess such a varied surface. The complete study of these forces belongs to a branch of science known as "geology".

Under the great oceans we meet with similiar variations of surface. The ocean floor is anything but level. It comprises great ridges, mountain-like in character, with intervening valleys. There are also great depressions on the ocean floor, known as "troughs". Here, again, we see that irregularity is a great characteristic of the earth's surface under the waters.

**The Materials of the Earth's Crust**

A very superficial observation of the earth's surface shows us that it can be divided into two great subdivisions. These are:

1. The loose covering of rocky waste and soil to which the name "mantle rock" has been applied.

2. Underneath this loose layer of mantle rock, and in many places protruding through it, are hard, firm layers of rock which are termed "bed rock".

The mantle rock has been formed, in every case, by the breaking down of bed rock by the forces of nature just considered. It is the composition and varieties of the bed rock that we now wish to consider.

These rocks, we shall find, are composed of other substances. For example, a piece of granite appears to be composed of three different sorts of material: a glassy and very hard material, a pinkish, greenish, or greyish-white substance, as well as a number of scales of shiny, thin-splitting material, mostly very small, but sometimes quite large. Such component parts of a rock are termed *minerals*.

A mineral is composed of *elements*, which are substances that chemists have not succeeded in resolving into anything simpler. Now, a mineral is not a rock, although rocks must be composed of minerals. What, then, is the difference between a mineral and a rock? Care must be taken to understand the difference between the two.

*A mineral* is a substance found in the earth, which always has a *definite* composition. There are hundreds of known minerals and they exist in many forms. Sometimes they have definite geometrical shape, when they are said to be "crystalline", while at other times they do not take on this definite shape, and are then said to be "massive".

It is very important to remember that the same mineral may occur in both states. Although there are hundreds of different minerals, it is found that the principal minerals concerned in forming rocks are relatively few in number. The most common are quartz, feldspar, calcite, mica, pyroxene, hornblende,

talc, dolomite, and iron pyrites. The minerals are brought together in many ways to form rocks.

**Rocks**

Rocks are mineral masses of sufficient size and importance to form essential members in the building of the earth's crust. They are distinguished from minerals

**Fig. 141.—Earthquake Fissure in Limestone**

by the fact that their composition is not definite. By this it is understood that the mineral quartz is always composed of a certain percentage of the elements oxygen and silicon. On the other hand the rock called granite, although it must have the three minerals, quartz, feldspar and mica, may have them present in any proportion.

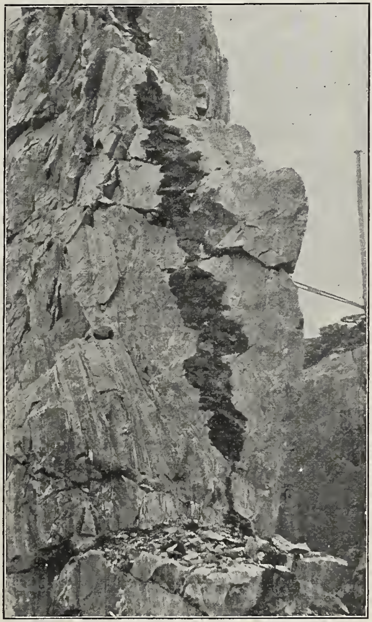


**Fig. 142.—Limestone, with Sheet of Igneous Rock. The Limestone has Flowed under Compression, and the Igneous Rock has Fractured**

We are now in a position to study bed rock. This is the hard, firm rock which underlies all the mantle rock and the oceans, and which penetrates to an unknown depth towards the centre of the earth. It often protrudes through the mantle rock, and may be exposed in river banks or artificial cuttings. Bed rocks are divided into three great classes:

1. *Stratified* or *Aqueous* rocks.
2. *Unstratified* or *Igneous* rocks.
3. *Metamorphic* or *Changed* rocks.

*Stratified rocks* have been produced by the agency of water, and owe their layer-like form to the fact that they were built up underneath the surface of the waters of lakes or seas, and have since been raised above the water level.

*Unstratified rocks* are the product of heat, and were once fluid. They are characterized by a glassy appearance. They are usually hard and speckled, and they make up the greater portion of the earth's crust.

*Metamorphic rocks* are either stratified rocks or unstratified rocks which have been caused to alter their appearance by pressure, heat or solution.

Shale, sandstone, limestone, and bituminous coal are examples of stratified or sedimentary rocks.

Granite, basalt, lava, feldspar, diorite, are igneous rocks.

Slate, marble, gneiss, mica, schist and anthracite coal are metamorphic rocks.

There is only one proper way to study rocks and minerals, and that is to collect and examine them. Mere book reading of the descriptions of these rocks is not sufficient, since they present many different aspects. Make a collection of the rocks and minerals about your district. Try to classify them. Ask others to assist you in doing this. You will find this a very fascinating collection to make.

## QUESTIONS

1. State three values to man of the fact that the surface of the globe is uneven, i.e., made up of elevations and depressions.
2. Distinguish igneous, stratified, and metamorphic rocks. Explain how each was formed. Give an example of each.
3. What are three causes of great elevations and depressions found on the surface of the earth?
4. Account for the location of sea shells in rock near the summit of a mountain.

5. How has the earth's crust over the igneous rocks been formed?

6. What are rocks? A mineral? The lithosphere?

7. Distinguish between rocks and minerals.

8. What is the main feature of the surface of the earth?

9. Indicate the distinguishing features of the three common types of rock found in the earth's crust.

## CHAPTER XXX

## MINERAL DEPOSITS

**Canada's Heritage**

The Dominion of Canada is now entering upon a new era in the utilization of her valuable natural resources. Great attention is being given to the development of these resources. Already important results have been obtained, and the possibilities of the future are of much greater promise. *"Canada offers today to the prospector the largest and most promising extent of mineral-bearing territory that remains unprospected."**

During the seven-year period 1921-1928 the mineral production of Canada rose from $172,000-000 in 1921 to $273,000,000 in 1928. This is an increase of more than $100,000,000, or 59 per cent. during that period. But there are other minerals besides those from which we extract metals. These are known as *non-metallic minerals,* and far outclass the metallic minerals in actual money value.

All these valuable materials of industry and commerce are extracted from mineral deposits of the earth. It is therefore of interest to see what science has to tell us about these mineral deposits. How did they occur, and how did they originate?

A mineral deposit is usually taken to mean one of those places in the earth's crust where there is a concentration of one or more minerals. When this con-

*The Canada Year Book, 1929. Chapter 12, page 343. Dominion Bureau of Statistics, Ottawa.

centration becomes enormously enriched with metals as compared with other parts, it is called an *ore deposit.* Should the enrichment be of non-metallic character, it is referred to simply as *mineral deposit.*

Ore deposits are largely produced by the circulation of waters in the earth's crust. These waters penetrate far into the crust, and as a consequence are subjected to great heat and great pressure. This enables them to dissolve minerals from the deep-seated hot rocks far down in the crust of the earth. The crust contains many cavities. Some of these are fractures or rents due to the action of volcanoes or earthquakes. Some are natural open spaces left when the rocks were laid down. Should underground water heavily charged with mineral matter enter one of these cavities, the pressure is relieved, and cooling takes place. This causes some of the mineral matter held in solution to be deposited on the walls of the cavity. In time these become filled with mineral matter and we have a mineral vein. This, in brief, is how mineral veins are formed.

**Importance of Minerals**

Modern civilization depends very completely upon a few mineral substances. The four most important of these are the minerals, coal and oil, and the metals, iron and copper. The bringing of these mineral substances under the control of man and the development of their uses is one of the greatest triumphs of science. We depend upon the continuous and plentiful supply of coal and oil to produce most of the power to run our great factories, and to operate the ships, locomotives and automobiles of our wonderful systems of transportation. Oil is gradually, but surely, lessening the labours of rural communities and making possible rapid communication between farm

and village and town and city. Iron is easily the most important metal known to man. See how we depend upon it for steel rails for our railroads, for steel plates to build our ships, for cast iron to construct our great engines.

We use fine steel to make girders and beams to build bridges and skyscrapers; also to make tools and thousands of other everyday and almost indispensable articles. Without plentiful supplies of copper to make electrical machines and wires, the modern applications of electricity would perhaps be impossible. In addition, coal gives us many dyes to produce the beautiful colours with which we dye the fabrics for the making of clothes, and materials for decorating our homes. From coal also are obtained wonderful drugs and other chemicals which do so much to alleviate human suffering. These are only a few of the many uses of these substances, but they indicate how much they would be missed if we were suddenly deprived of them.

**Origin and Mode of Occurrence of Iron Deposits**

There are many kinds of minerals which contain iron as their principal constituent. There are, however, only four which are valuable as a source of iron. The great iron deposits of the Lake Superior region are soft earthy masses of iron oxides. They have been produced by the alteration of huge beds of iron carbonate through the action of the atmosphere. The original deposition of these ores is believed to have taken place in the very early periods of the earth's history, when they were separated from the heated waters welling up from the hot rocks of that period by the action of a type of algae. These iron ore deposits are not veins, but occur as beds filling basin-like depressions.

So far no iron has been produced in Alberta, Sas-

katchewan, or Manitoba. Some small and low-grade deposits of iron ore have, however, been found in these provinces. Ontario is much the most important iron-producing province of Canada, with Nova Scotia ranking second. Iron deposits of considerable magnitude are known to exist in Quebec and British Columbia.

**Copper Deposits**

There are a large number of copper-bearing ores. Copper is also found native, that is, in the metallic state in the rocks. Copper ores are most frequently found as veins. These veins are sometimes like sheets running down into the earth. Others are masses of tiny stringers more or less closely bunched together. Some form lattices of vein-stuff in the rocks. All copper deposits are the result of circulating waters charged with copper compounds depositing mineral matter in the cavities. The copper mining industry is developing at a very rapid rate in Canada. British Columbia is the chief producing province, with Ontario and Quebec following. Extensive copper deposits have been found in the Flin-Flon area of Northern Manitoba, and are now being worked.

**Salt Deposits**

Salt deposits may be formed by two main methods:

1. By circulating ground waters traversing rocks containing suitable minerals, which are dissolved, so that the salt is re-deposited in another place.

2. By isolated bodies of sea water being evaporated, and the salt residue being covered by soil which has afterwards been compressed into rock. This explains how thin beds of salt have originated.

Thick beds of salt are believed to have been formed by the drying up of large salt lakes, such as the Caspian Sea, Great Salt Lake, and the Dead Sea, during

periods of great aridity. The wind-blown dust of these dry times covered the salt over. This was finally consolidated into rock, and the salt was sealed up.

Many lakes and springs in Alberta contain salt, and there is a small production of salt from the province. In Northern Alberta, drilling by the Provincial Government proved the existence of a thick bed of rock salt at McMurray.

Ontario is the leading salt-producing province, with Windsor as the centre of the industry. Nova Scotia has important salt deposits at Malagash, Cumberland County, which supply the fishing industry of the province with an excellent quality of salt.

Coal is the remains of plants of a former age preserved between layers of sedimentary rocks and converted into carbon. It was formed by vegetable matter

*From Sargent's Plants and Their Uses*

Fig. 143.—Giant Tree Ferns
Plants like these formed the coal strata ages ago.

in huge quantities decaying under water, the land subsiding and water overflowing it. The rivers poured their silt over the partially decayed plants. Next the land rose again. Plants repopulated it, swamps reappeared, vegetable matter accumulated in them, and the land sank again. This cycle of operation may have been repeated many times, forming a succession of coal seams one above the other. The coal formation cycle is:

**Coal Deposits**

1. Uplift of the land.
2. Abundance of vegetation.
3. Depression.
4. Peat formation, or carbonization.
5. Silting over.
6. Consolidation.

Alberta is said to contain 87 per cent. of all the coal in Canada in her coal fields, and is now the leading producer of coal in the Dominion.

The Alberta coal-mining industry is mainly centred around Lethbridge, The Crow's Nest Pass, Drumheller, Canmore, Nordegg, Edmonton and Coalspur. Nova Scotia, which used to be the leading coal-producing province of Canada, is pressing hard for second place. British Columbia has important coal deposits and is our third largest producer in the Dominion.

**Oil**

Oil is a liquid mineral found accumulated under certain conditions in the pores of certain rocks, like sandstones, shales, dolmite and limestones. These accumulations are often found thousands of feet below the surface. They are obtained by drilling wells to tap them. Sometimes the pressure on the oil is great enough to cause the oil to spout from the well with great force. This is called a *gusher*. Other wells do not develop such high pressure, and the oil is pumped from them.

The origin of petroleum is believed to be plant and animal matter. It is supposed that such material accumulated under water and was acted upon by bacteria while freshly deposited. This resulted in the formation of petroleum, which later was squeezed out of the shales or mud rocks by the pressure of overlying accumulations of sediment into the porous beds where it remained stored. It must be clearly understood that

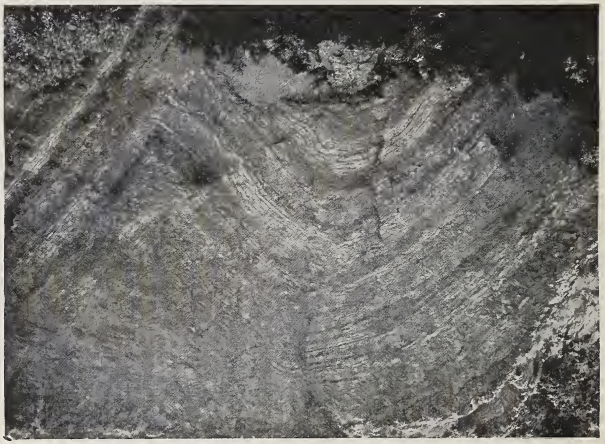


**Fig. 144.—Symmetrical Folds; Anticline on Left, and Syncline on Right**

there are no such things as underground lakes of oil. The most favourable condition for the storage of oil is a layer of porous rock, sandwiched between layers of shales or clays which cannot be penetrated by the oil.

If the layers are folded into a wave-like form we have a succesion of crests or troughs. Geologists call such crests *anticlines*, and the troughs, *synclines*. The oil

and gas accumulate in the anticlines whilst water is stored in the synclines.

Alberta produces about 77 per cent. of all the petroleum obtained in the Dominion. The Turner Valley Field, about 40 miles south of Calgary, is the principal source of production. Another producing oil field in the province is at Wainwright about 120 miles east of Edmonton. Many other potential oil fields in the

**Fig. 145.—Turner Valley Oil Field, Alberta**

province are now being tested by drilling. There is also an oil refinery at Calgary. Ontario is also an oil producer, the oil fields being situated between Lake Huron and Lake Erie. Of recent years the oil yield from Ontario has been declining. Sarnia has a great oil refinery.

*Natural gas* has the same origin as the oil with which it is often found associated. It is stored in almost exactly the same manner as the oil. Natural gas pro-

ducing fields of Alberta are situated at Medicine Hat, Bow Island, Viking, Foremost, Turner Valley, Fabyan and Pelican Rapids. There are also many natural gas fields in Ontario, which province accounts for about 53 per cent. of the Canadian production.

## QUESTIONS

1. What are ore deposits? How are they different from mineral deposits?
2. What are mineral veins? Explain their formation.
3. Outline the theory which explains the formation of a coal field.
4. Write a note on the importance of iron.
5. Explain how the Lake Superior iron ore deposits were formed.
6. What are some important uses of copper? Explain how copper ore deposits originate. Where are the chief copper-producing centres of Canada.
7. Explain the formation of salt beds found in the earth.
8. What is mineral oil or petroleum? Point out its value in our modern world.
9. Explain the origin and mode of occurrence of petroleum in the earth.

# PART SEVEN

# THE SOLAR SYSTEM

## CHAPTER XXXI

## SUNS AND STARS

Because of repeated reference to the sunlight and the sun's energy, the student must, by now, have begun to realize something of the importance of the sun. All thoughtful persons know that we owe much to the sun, but they do not realize how completely the human race is dependent upon the energy so lavishly thrown out from the sun. Without the steady attraction of the sun on the earth, our planet would fly away to unknown regions in the depths of space.

**Our Dependence Upon the Sun**

Deprived of the continuous supply of heat now received from the sun, evaporation would stop, and there would therefore be no rainfall. Rivers would soon cease to flow. Vegetation would die off, and man and animals would perish for lack of food. The whole earth would speedily become a cold, lifeless world. All our food is manufactured by the help of the light given by the sun. To sunlight we owe all the wood, coal and oil, whose energy we use, by burning them as fuels, to turn the machinery of our great factories and to operate our automobiles, trains, and steamships. Let us therefore try to get some idea about this wonderful body to which we, on the earth, owe so great a debt.

The sun is a huge sphere, a little less than a million miles in diameter. It is extremely hot. Astronomers

**Fig. 146.—Telescope**
The 72-inch reflecting telescope at Dominion Astrophysical Observatory, Victoria, B.C. At the lower extremity is attached the spectroscope.

believe the temperature at its surface to be probably ten thousand degrees Fahrenheit. They believe it to be more or less solid at its centre, while its surface is in a state of wild disturbance. Great explosions are known to take place within it. These fling out huge masses of white-hot material and burning gases with great velocity.

**The Sun**

It is difficult to give an idea of the size of the sun. Its diameter is more than one hundred times that of

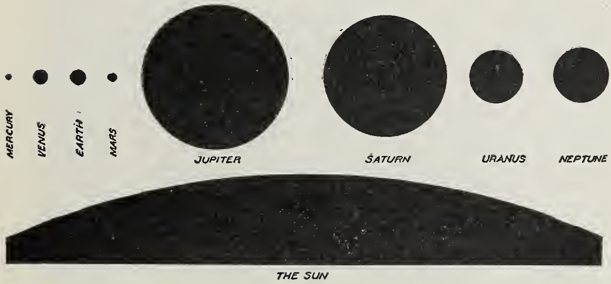



**Fig. 147.—Relative Dimensions of Sun and Planets**

the earth. It is computed that more than a million bodies of the size of our earth would be necessary to make a ball as large as the sun. But although to us the sun seems so huge, it is really very small when compared with some of the other suns of the universe. Most of the stars we see with the naked eye are immense suns, much larger than our sun and millions of times greater than the earth. Some stars give out ten thousand times as much light as our sun. They appear so small because they are so far away. The nearest star to us is a very large sun called Alpha Centauri. It is so far distant that light, travelling at 186,000

Fig. 148.—Photograph of the Corona at the Total Eclipse of the Sun, May 28, 1900 (Barnard and Ritchie)

miles per second, takes more than eight years to cross the space between it and the earth.

Our sun is about 94 million miles away from us. To us this is a stupendous distance, but in comparison with star distances it is very small.

It is believed that each star is the centre of a system of bodies which revolve around it and to which it furnishes light and heat, in much the same manner as the sun provides light and heat to the members of its family.

**Constellations**

Constellations are groups of stars, which to observers on the earth appear to be moving as a unit. They really have no relationship to each other, their apparent grouping being merely the result of perspective.

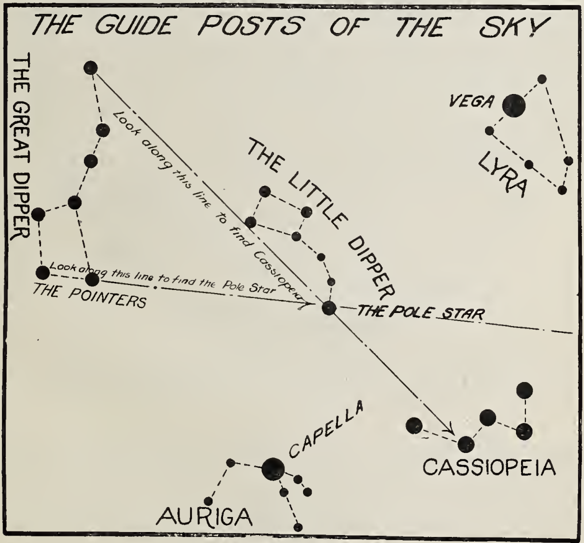



**Fig. 149**

In olden days the ancient watchers of the skies gave names to these groups, on account of their fancied resemblance to the forms of familiar things. If one observes the positions of some of these groups in the early evening, and again later at night it will be noticed that they have moved across the sky in a

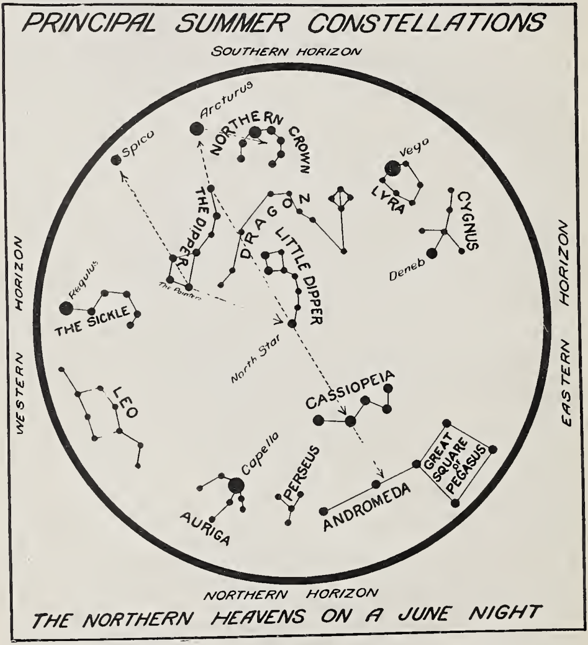
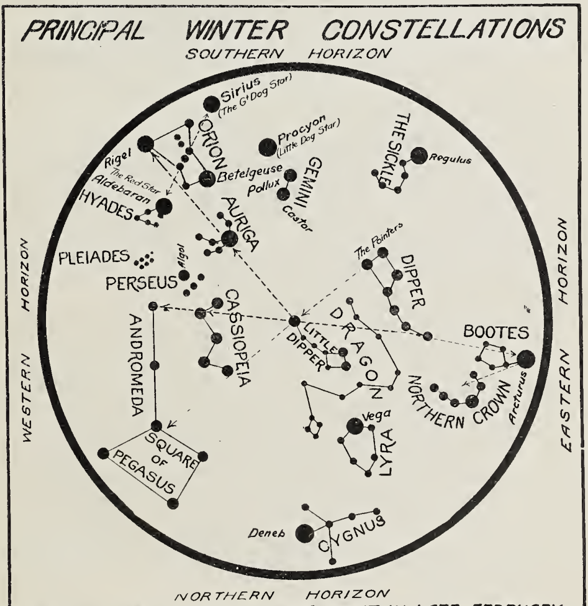



Fig. 150

westerly direction. This apparent movement of the group is due to the rotation of the earth. It is exactly like the apparent motion of the sun across the sky. Although we know that the stars must be travelling, we

cannot say what their direction is, nor around what point they are circling. Some of the constellations appear to circle around the North Pole of the earth once every twenty-four hours. These stars never set. We cannot, however, see them during the day, since the brighter light of the sun outshines the light we receive



THE NORTHERN HEAVENS ON A NIGHT IN LATE FEBRUARY

**Fig. 151**

from them. Such constellations are called circumpolar stars. Some of the best known constellations are the Big Dipper, Little Dipper, Orion, Pegasus, and the Northern Crown.

**Finding the Constellations**

In order to find these constellations it is necessary first to find the Big Dipper. If you do not know this constellation, get someone to point it out to you. It is a very conspicuous group and, once pointed out, can always be easily recognized. The two outer stars of the bowl are called pointers, since a line drawn through them, prolonged about five times the distance between them, passes through the Pole Star. The position of the Pole Star gives a true north direction.

If the line be prolonged still farther, it will eventually reach a constellation that looks very much like a badly made "W" straggling across the sky. This is Cassiopeia. It is always on the opposite side of the North Star to that taken by the Big Dipper. The North Star is the end star of the handle of the Little Dipper.

In order to find the other constellations we must now locate two very bright stars called Capella and Vega. To find them, locate the pointers, and then Cassiopeia. Capella is the brightest star between the bowl of the Big Dipper and Cassiopeia. Vega is the brightest star between these two constellations on the opposite side of the Pole Star. Capella belongs to the constellation of Auriga, while Vega is the only bright star in the somewhat triangular shaped constellation known as Lyra.

The constellation of Pegasus is only visible in northern latitudes. To find Pegasus, look along an imaginary line joining the Pole Star with the right-hand star of Cassiopeia. Prolong this direction for about its own length, and it passes through two stars which form the left-hand top and bottom corners of a great square. This square is the constellation of Pegasus.

Orion is the finest constellation in the skies. It is only visible to us in the northern latitudes in the winter and early spring. A line from the North Star passing through the bright star Capella will pass through Orion.

The constellation of the Pleiades is found near a red star called Aldebaran, between the constellations of Orion and Cassiopeia. It is a famous and beautiful constellation frequently referred to in the literature of all nations.

The constellation of the Northern Crown may be found by following the line pointing along the handle of the Big Dipper away from the bowl, until you find the very bright star Arcturus. Look to the left of this star, and the Northern Crown is the semicircle of stars with a very bright one near its centre.

## QUESTIONS

1. What are the stars? How large is our sun compared with most of the stars?
2. Mention some effects which would follow if we were to be deprived of the sun's heat.
3. Mention six things which we owe to the light energy received from the sun.
4. Explain how to locate the North Star.
5. What constellations and principal stars may be considered the guide posts of the skies at night and why?
6. Tell how to locate the following constellations: Pegasus, Pleiades, Orion, Auriga, Cassiopeia.
7. What bright star might be confused with the planet Mars, and why?

## CHAPTER XXXII

## EARTH AND MOON

The sun on its journey through space is accompanied by a number of celestial bodies. These are the eight planets, some of which are similarly accompanied by satellites, which we call moons. In addition, there are a large number of planetary fragments revolving about the sun along paths which lie between the orbits of Mars and Jupiter. These are called Asteroids or Minor Planets. There are also numerous curious bodies called comets.

**Our Solar System**

All these objects are compelled by the gravitational attraction of the sun to whirl around it. The whole system is known as the Solar System, and it is thought that it was all at one time part of the sun's mass, but finally separated from it. All the planets are dependent upon the sun for their light and heat energy. We see them all by the sunlight reflected from their surfaces. They are too cool to give off light themselves. In this way they are much different from the stars studied in the last chapter.

**The Planets**

The most important members of the sun's family are the eight major planets: Mercury, Venus, Earth, Mars, Jupiter, Saturn, Uranus and Neptune. They are named here in the order of their distances from the sun. Jupiter is the largest planet and Mercury the smallest. Venus is by far the brightest and most conspicuous. It is more like the earth in size, density and

general make-up than any of the others. However, by being about 25 million miles nearer the sun, it receives much more heat and light than does the earth. Mars is noted for its bright red light and its curious markings, which have become known as canals, although it is not at all certain that they are such things. In fact, few astronomers believe such to be the case. Mars is accompanied by two moons.

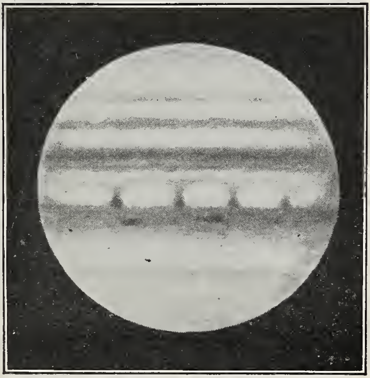


Fig. 152.—Jupiter (Barnard)

Jupiter is remarkable for the coloured bands around its surface running parallel to its equator. It is believed that Jupiter is still very hot. It is accompanied by nine moons, four of which may be seen through a field glass.

Saturn is noted for its wonderful rings and ten moons, one of which revolves around the planet in a direction opposite to the rest. All these planets have been known since ancient days. The improvement in telescopes made by Herschel during the reign of George III. led to the discovery of the other two: Uranus, which was discovered by Herschel, and Neptune, discovered through mathematical calculations made independently by Leverrier in France and Adams in England. They are so far away that little

is known about them. Uranus has four moons and Neptune one.

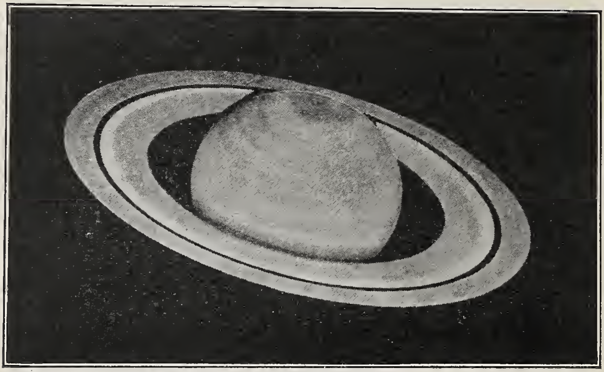


**Fig. 153.—Saturn with Rings Tilted at Greatest Angle (Drawing by Barnard)**

**The Earth**

We are, of course, more particularly concerned with the revolution and rotation of the earth than we are with those of the other planets. This is because such motions have very marked effects upon the conditions under which we are compelled to live. The Earth, in common with all heavenly bodies, has two principal motions: rotation about its axis, and revolution around the sun. The actual path followed by the Earth in its journey around the sun is called its orbit. In form it is an ellipse, although it more nearly approaches a circle than most people suppose. The sun does not always occupy the same relative position to the Earth during its journey around the sun. At times it is nearer the Earth than at others. When the sun is nearest the Earth it is said to be at perihelion, and at aphelion

when farthest away. We must not jump to the conclusion that it is summer when the sun is at perihelion. This is not so, for perihelion occurs during the winter. The time taken to complete one revolution of the Earth around the sun is one solar year. This is accomplished in almost 365¼ days.

In studying the Seasons it is necessary to consider the position of the earth's axis with respect to the plane of its orbit. The Earth's axis is not perpendicular to the plane of the orbit but slopes away from the vertical at an angle of 23½ degrees. This slanting of the Earth's axis has many important effects. It fixes the location of the Arctic and Antarctic circles, and also locates the position of the Tropics of Cancer and Capricorn. The direction of slope of the Earth's axis is always the same, so that, as it travels along its orbit, it first leans towards the sun, is then parallel with it, is next leaning away from the sun, and is again parallel with it. It is this peculiarity about the inclination of the Earth's axis which causes the seasons, because it sometimes points the North Pole towards, and the South Pole away from, the sun. For a similar period during its revolution, the South Pole is held towards the sun while the North Pole is pointed away. At two points in the earth's orbit the Poles are held equidistant from the sun. This behaviour also produces the varying height of the sun above the horizon at different times throughout the year. The inclination of the Earth's axis, then, is the cause of the seasons.

**Tropics and Seasons**

The daily motion of the earth produces day and night. The time occupied by one rotation fixes the length of a solar day. As the earth rotates, it brings every point on its surface successively under the sun.

This makes it appear as if the sun itself were passing over the earth. The lines joining all the points on the circumference of the earth which are thus directly opposite the sun, are called meridians, hence, in common language, the sun is said to *cross the meridian.* The time taken from one crossing to the next is one day. Owing to many causes, the earth is sometimes pulled a little this way or that from its true path. This causes the lengths of the solar day to vary slightly; so, in order to fix a definite unit of time, a certain meridian is chosen, and the average length of these times in crossing the meridian determines for us the mean solar day which, divided by 86,400, gives us the standard second. In Canada, the time is calculated from the time the sun crosses the meridian passing through the axis of a telescope fixed in the Dominion Meterological Observatory at Toronto. All Canadian clocks are kept right with this time each day.

**Standard Time**

It is quite obvious that in large countries the time of the meridian crossing of one place would not be convenient to use in another. Then again, it would be just as inconvenient for each community to use its own time. This difficulty was encountered by the C.P.R. in operating its trains across the Dominion. In trying to solve the difficulty, Sir Sandford Fleming invented what he called "Standard Time". It is a time calculated from a certain meridian within a given belt of country, which is used by all places within that belt. Since the earth rotates through 360 degrees in 24 hours, it takes one hour to turn through 15 degrees. This was made the basis of dividing the earth into time belts, each of which is 15 degrees wide. The time used as Standard Time within these belts is calculated from the crossing of the meridian passing through the centre of the belt.

On passing from one belt into another the watch of a traveller is advanced or put back one hour according to the direction he takes.

**The Moon**

The earth is accompanied on its journey around the sun by a satellite which we call the Moon. It is a relatively small body, having a diameter of about 2,163 miles. It is about 240,000 miles away from the earth. It revolves about the earth once in about 29½ days. This period is known as a lunar month. The moon also rotates on its axis, but we are never able to see the other side of the moon since it always presents the same face to us. The time of rotation of the moon is 27½ days. The motions of the moon cause:

1. The phases of the moon.
2. Eclipses of the sun and moon.
3. Tides.

*Phases of the Moon*—This term means the different appearances of the illuminated surface of the moon. They are due to the fact that the moon is constantly changing its position with reference to both the sun and the earth. In Fig. 154, the moon at M1 is between the earth and the sun. Its dark side is then turned toward the earth, and we receive no light from it. This is the New Moon. About seven days later, when the moon has completed a quarter of its revolution, it reaches the position M2. Half of its illuminated disc is turned to the earth, and it is seen as a half circle. This is known as the First Quarter, while at M4 it presents the same shape and is known as the Third Quarter. In passing from M1 to M2, it appears as a crescent, as in the diagram. When the moon has reached the position M3, half of its revolution has been performed and the whole of its illuminated side is turned to earth, giving us what we call the

Full Moon. As it passes from M2 to M3, it grows from half a circle to a full moon. During that time it is said to be a gibbous moon. From M1 to M3, the moon has been growing in size or "waxing". From M3, through M4, back to M1, it is gradually diminishing in size and is said to be "waning".

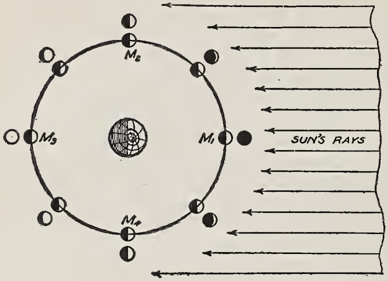



**Fig. 154.—Explanation of the Moon's Phases**

**Eclipses**

There are two kinds of eclipses: Solar and Lunar. *Solar eclipses* are caused by the passage of the moon between the sun and the earth (See Fig. 155). *Lunar eclipses* are caused when the earth comes between the sun and the moon, and casts its shadow on the moon's disc.

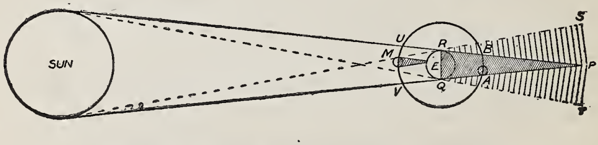



**Fig. 155.—Eclipses of the Moon and Sun**

*E* represents the earth, and *M* and *A* represent two possible positions of the moon. When the moon is in the position *M*, an eclipse of the sun takes place; those people living within the zone covered by the tip of the moon's shadow see a total eclipse of the sun. When the whole of the moon is in that part of its orbit marked by the line *AB* it is in total eclipse. When it is in either of the regions *TQP* or *SRP*, a partial eclipse of the moon occurs.

The regular rise and fall of the water on the sea shore each day rarely fails to excite the interest of visitors to the sea coast. These great regular movements of the water are known as tides. They consist of a regular rise and fall of water twice a day. When the water is rising it is *flood tide*; when it is falling it is *ebb tide. High water* occurs when the level is highest, and *low water when* it is lowest. The average interval between

**Tides**

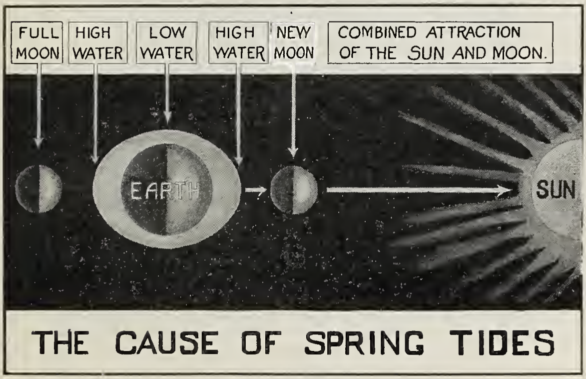



**Fig. 156**

high water on successive days is 24 hours 51 minutes, which is the same as the average interval between two successive passages of the moon across the meridian. This makes it certain that there must be a close connection between the moon and the tides.

The range of the tides when the moon is new or full is much greater than the average. High water rises higher, and low water falls lower, without affecting mean sea-level. These are called *spring tides.*

*Neap tides,* which occur at the first and last quarters of the moon, have the smallest range.

Careful study of the tides has shown that they are due to the gravitational pull of both moon and sun on the earth. The moon exerts the greater force because it is so much nearer to the earth than is the sun.

*The tide-raising force* is due to the difference between the gravitational attraction of the moon on the different parts of the earth. The moon attracts the

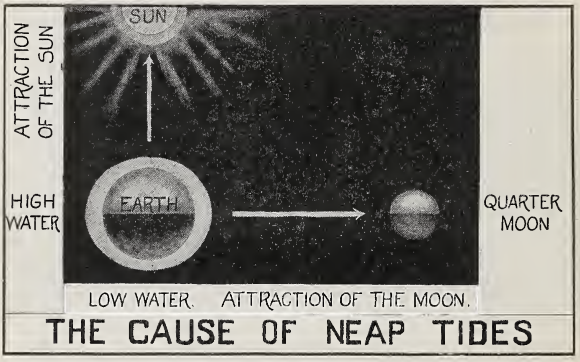



Fig. 157

earth, including the ocean, directly beneath it, but the attraction produces a greater effect on the fluid ocean than on the solid earth, causing it to heap up in the direction of the gravitational pull. On the side of the earth farthest from the moon the tendency is for the earth to be pulled away from the ocean, which causes a heaping up of the latter similar to that on the near side. This explains a phenomenon which might otherwise puzzle us, namely that high water occurs at the same time at points on the opposite sides of the earth. Owing, however, to the irregular coastlines of the

continents and the rotation of the earth, the time of occurrence of high water and the height it reaches vary greatly at different places.

*Spring and neap tides*—We said above that both sun and moon took part in producing the tides, though the moon exerts the greater force. It is the interaction of solar and lunar gravitation that produces spring and neap tides. Study Fig. 156, and you will see that at new and full moon the attractions of the sun and moon act together, owing to their relative positions in the heavens, and cause an unusually high tide. On the other hand, when the moon is in its first or last quarter, the solar attraction opposes that of the moon. Hence the tide is low. (See Fig. 157.)

Tides are of considerable importance to navigators, owing to the changes of depth and the currents they produce; while in many places, such as shallow harbours, the tides control daily life more closely than almost any other natural phenomenon.

## QUESTIONS

1. What is included in the solar system? Explain the relation of the different parts of the system to each other.
2. Explain the two important effects upon the earth that the two great motions of the earth produce.
3. Why is the heating effect of the sun less in winter than in summer?
4. Explain, using a diagram, the regular succession of summer and winter as we experience it year after year in our portion of the globe.
5. What is standard time? Why was it necessary to adopt standard time? Where was it first used and who invented it?
6. Account for the four phases of the moon and illustrate with diagram.
7. Using diagrams make clear:
    1. An eclipse of the sun.
    2. An eclipse of the moon.
8. Explain the formation of the spring tides.
9. Tell how the production of a high tide on the side of the earth opposite the moon is accounted for.

# APPENDIX

## INTERNATIONAL METRIC SYSTEM

In this system the fundamental unit is the metre—the unit of length. From this the units of capacity (litre) and of weight (gram) were derived. All other units are the decimal subdivisions or multiples of these. For all practical purposes 1 cubic decimetre equals 1 litre, and 1 litre of water weighs 1 kilogram.

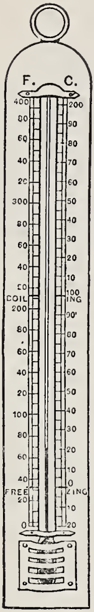
| Units of Length | | Units of Capacity | | Units of Weight | |
|---|---|---|---|---|---|
| millimetre | = 0.001 metre | millilitre[1] | = 0.001 litre | milligram | = 0.001 gram |
| centimetre | = 0.01 metre | centilitre | = 0.01 litre | centigram | = 0.01 gram |
| decimeter | = 0.1 metre | decilitre | = 0.1 litre | decigram | = 0.1 gram |
| METRE | = 1. metre | LITRE | = 1. litre | GRAM | = 1. gram |
| dekametre | = 10. metres | dekalitre | = 10. litres | dekagram | = 10. grams |
| hectometre | = 100. metres | hectolitre | = 100. litres | hectogram | = 100. grams |
| kilometre | = 1000. metres | kilolitre | = 1000. litres | kilogram | = 1000. grams |

[1] 1 millilitre = 1 cubic centimetre. 1 cubic centimetre of water weighs 1 gram

### Important Equivalents

| | |
|---|---|
| 1 metre | = 39.37 inches (1 inch = 2.54 centimetres) |
| 1 foot | = 30.5 centimetres |
| 1 kilogram | = about 2.2 pounds (1 pound = 453.6 grams) |
| 1 litre | = about .88 quarts |
| 1 cubic foot water | = 62.4 pounds |
| 1 gallon of water | = 10 pounds |
| 1 atmosphere | = 14.7 pounds per square inch |
| | = 76 centimetres (30 inches) mercury |
| | = 1034 centimetres (34 feet) water |

# COMPARISON AND CONVERSION OF TEMPERATURE SCALES




| | Centigrade | Fahrenheit |
|---|---|---|
| Boiling Point | 100 | 212 |
| | 95 | 203 |
| | 90 | 194 |
| | 85 | 185 |
| | 80 | 176 |
| | 75 | 167 |
| | 70 | 158 |
| | 65 | 149 |
| | 60 | 140 |
| | 55 | 131 |
| | 50 | 122 |
| | 45 | 113 |
| | 40 | 104 |
| Body Temperature | 37 | 98.6 |
| | 35 | 95 |
| | 30 | 86 |
| | 25 | 77 |
| Room Temperature | 20 | 68 |
| | 15 | 59 |
| | 10 | 50 |
| | 5 | 41 |
| Freezing Point | 0 | 32 |
| | | 0 |

For every five degrees on the Centigrade scale there are nine degrees on the Fahrenheit scale

Rule: To convert Fahrenheit to Centigrade Subtract 32 and Multiply by 5/9.

To convert Centigrade to Fahrenheit Multiply by 9/5 and add 32.

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